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Indian Standard

GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 6 MAINTAINABILITY VERIFICATION

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 12 *July* 1984

Indian Standard

GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 6 MAINTAINABILITY VERIFICATION

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GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 6 MAINTAINABILITY VERIFICATION

0. FOREWORD

0.1 This Indian Standard (Part 6) was adopted by the Indian Standards Institution on 12 July 1983, after the draft finalized by the Reliability of Electronic and Electrical Components and Equipment Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 Maintainability, a characteristic of design and installation, and affected by various personnel and logistic factors is one of the many system requirements which shall be considered during the system engineering effort. The degree of maintainability achieved depends upon the requirements imposed and the emphasis of management of maintainability. This standard defines a planned programme to be implemented for verification, demonstration and evaluation of maintainability.

0.3 This standard is Part 6 of the Guide on Maintainability of Equipment. Final publication of the complete series is expected to take some time but since each Part is able to make a contribution to the needs of other ISI Technical Committees it has been decided to publish each part separately. The other parts of this standard are as follows:

Part 1	Introduction to maintainability
Part 2	Maintainability requirements in specifications and contracts
Part 3	Maintainability programme
Part 4	Test and diagnosis procedures
Part 5	Maintainability studies during the design phase
Part 7	Collection, analysis and presentation of data related to maintainability

0.4 In the preparation of this standard, assistance has been derived from MIL-STD-471A (1973) 'Maintainability Verification/Demonstration/Evaluation' issued by the Department of Defence, United States of America (USA).

0.5 This standard is one of a series of Indian Standards on reliability of electronic and electrical components and equipment. A list of standards published so far in this series is given on page 74.

1. SCOPE

1.1 This standard (Part 6) deals with the procedures and test methods for verification, demonstration and evaluation of qualitative and quantitative maintainability requirements. It also provides for qualitative assessment of various integrated logistic support factors related to and aiming at the achievement of maintainability parameters and equipment down time, for example, technical manuals, personnel, tools and test equipment, maintenance concepts and provisioning.

NOTE — This standard is intended for use when verification, demonstration and evaluation of maintainability requirements for electronic and electrical equipments and parts procurement is required. The verification, demonstration and evaluation of achievement of maintainability requirements shall normally be conducted in 3 (three) phases as described in **4.1.2** and also in conjunction with verification, demonstration and evaluation of the requirements for total integrated logistic support unless otherwise stipulated in procurement standards.

2. TERMINOLOGY

2.1 For the purpose of this standard, the terms and definitions specified in IS : 1885 (Part 39)-1979* in addition to the following, shall apply.

2.1.1 *Maintenance Task* — The maintenance effort necessary for retaining an item in, changing to, or restoring it to a specified condition.

NOTE — The procurement agency will provide to the maintenance agency any terms that will be considered synonomous with the term 'task' and will provide definitive criteria for determining different types of maintenance tasks and the timing of the tasks during verification/demonstration or evaluation.

2.1.2 *Maintainability Model* — A quantifiable representation of a test or process, the purpose of which is to analyse results to determine specific relationships of a set of quantifiable maintainability parameters.

2.1.3 *Verification* — The effort of the manufacturer, from the date of accepting the supply order through hardware development up to the configuration item (CI).

NOTE — This effort includes determination of the accuracy of the analytical data (predicted data) obtained from the maintainability engineering analysis and its constant updatement, identifying maintainability design deficiencies and gaining progressive assurance that the maintainability of the item can be achieved and demonstrated in subsequent phases.

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*Electrotechnical vocabulary: Part 39 Reliability of electronic and electrical items (*first revision*).

2.1.4 *Demonstration* — The joint effort of the manufacturer and the procurement agency to determine whether the specified contractual requirements of maintainability have been achieved.

2.1.5 *Evaluation* — The effort of the procurement agency in determining, at all levels of maintenance, the impact of the operational, maintenance and support environment on the maintainability parameters of the item and to demonstrate various levels of maintenance tasks.

2.1.6 *Development Test and Evaluation* (*DT and E*) — Test and evaluation which focuses on the technological and engineering aspects of the systems, sub-system or equipment.

2.1.7 *Operational Test and Evaluation* (*OT and E*) — Test and evaluation which focuses on the development of optimum tactics, tachniques, procedures and concepts for systems and equipment, evaluation of reliability, maintainability and operational effectiveness and suitability of systems and equipment under realistic operational conditions.

2.1.8 *Maintenance Concept* — A description of the planned general scheme for maintenance and support of an item in the operational environment.

2.1.9 *Maintenance Environment* — The climatic, geographical, physical and operational conditions (for example, combat, mobile) under which an item will be maintained.

3. OBJECT

3.1 The object of this standard is to establish uniform procedures, test methods and requirements for verification, demonstration and evaluation of the achievement of specified maintainability requirements and to assess the impact of planned logistic support.

4. REQUIREMENTS

4.1 General

4.1.1 Maintainability verification, demonstration and evaluation shall be performed in accordance with the maintainability verification/demonstration/evaluation test plans given under **5**, which shall be prepared by the manufacturer and approved by the procurement agency.

4.1.2 The test plan when applied to the system level shall include the three phases, namely, verification (Phase I), demonstration (Phase II) and evaluation (Phase III). When the test plan is applied to less than a system level, the procurement agency shall specify the applicable phases. Figure 1 gives a general time phase relationship of the three phases which may differ for individual requirements. The procurement agency will provide guidance to the manufacturer as to the relationship between system life cycle phase and the verification/demonstration/evaluation phases. For the complete accomplishment of the procedures contained in this standard the detailed information given in the manufacturer's maintainability analysis should be utilised [*see* IS : 9692 (Part 3)-1981*].

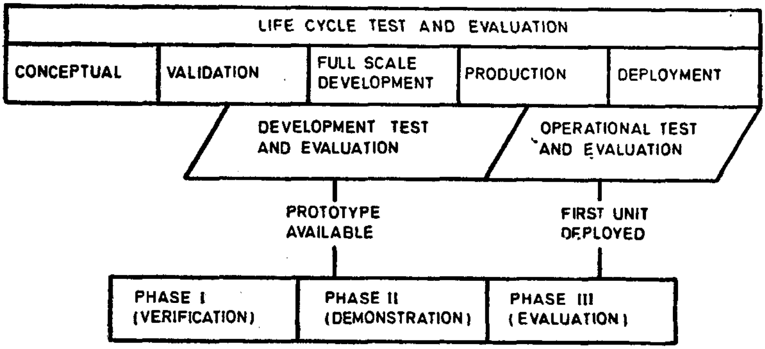

FIG. 1 TIME PHASED CHART FOR MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION

4.1.3 The maintainability analysis of the manufacturer shall contain a comprehensive description of the predicted maintenance tasks which shall include the following:

a) Failure mode or symptom and 'how malfunction code' which would initiate the corrective maintenance task;

b) Frequency of occurrence of each failure mode and symptom of every maintenance task;

c) Appropriate 'action taken codes' and 'work unit codes' for each maintenance task;

d) Predicted times for each element of maintenance time;

e) Skill levels and number of people required for each maintenance task;

f) Support equipment and tools required for each maintenance task;

g) Technical order interface for each maintenance task;

h) Identification of preventive maintenance tasks; and

j) Identification of those maintenance tasks which are not normally or under any circumstances permitted to be performed concurrently with other maintenance tasks. It is assumed that all other maintenance tasks can be performed unrestricted by the performance of on going maintenance.

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*Guide on maintainability of equipment: Part 3 Maintainability programme.

4.2 Verification (Phase I)

4.2.1 During Phase I, the manufacturer shall conduct an incremental verification effort, commencing with initial design and continuing through hardware development from components and materials to the configuration item. The basic objectives of this phase are:

a) Verification and updatement of the manufacturer's maintainability model;

b) Economical correction of design deficiencies and providing assurance that maintainability requirements will be achieved and demonstrated, by performing early in the design process maintainability verifications such as limited low confidence maintainability tests, time motion measurements or such other tests as may be proposed by the manufacturer subject to the approval of the procurement agency; and

c) Provision of progressive assurance that the maintainability requirements can be achieved and demonstrated and that elements of the integrated support plans directly related to maintainability are valid.

4.2.2 Maximum use shall be made of the data resulting from maintenance performed in conjunction with such tests as development, prototype, mock-up, qualification and reliability tests. When the procurement standards specify that the maintainability demonstration shall be part of Phase I, the maintainability demonstration and requirements of demonstration (Phase II) shall apply.

4.3 Demonstration (Phase II)

4.3.1 The object of demonstration (Phase II) is to determine during development test and evaluation (DT and E) whether all specified maintainability contractional requirements, except as noted under evaluation (Phase III) have been achieved. During this phase, the procurement agency will manage and conduct a maintainability demonstration as part of the total system demonstration. For those procurements which do not require a total system demonstration, the maintainability demonstration to be conducted in this phase shall be an extension of Phase I. To assure acceptability of recorded data and resultant analysis, the manufacturer shall participate in this effort to the extent provided under **7**. The following requirements (*see* **4.3.1.1** to **4.3.1.12**) shall apply to all maintainability demonstrations. Additional requirements or changes may be imposed on individual needs.

4.3.1.1 The maintainability demonstration shall be conducted in an environment which simulates, as closely as practicable, the operational and maintenance environment planned for the item. This environment shall be representative of the working conditions, tools, support equipment, spares, facilities and technical publications that would be required during operational service use at the maintenance level defined in the approved maintenance plan.

4.3.1.2 The personnel of the inspection authority named in the contract and assigned to the test organization shall operate and maintain the demonstration items (*see* **5.2.3** and **7.2**). When demonstration is conducted as an extension of Phase I, the procurement authority shall specify the personnel (pertaining to the inspection authority named in the contract or the manufacturer) who will operate and maintain the items.

4.3.1.3 In conjunction with the maintainability demonstration, the approved integrated support plan, when required and established by the manufacturer, sealed to the number of test items employed in the demonstration, shall be implemented by the test team to identify the logistic support provided during this phase.

4.3.1.4 All maintenance data including depot level, shall be recorded and reported to the test team as specified by the procurement agency.

4.3.1.5 Unless otherwise approved by the procurement agency, the configuration of the items of the system selected for maintainability demonstration shall be documented and certified by a physical configuration audit (PCA).

4.3.1.6 Unless otherwise approved by the procurement agency, all support equipment used during the demonstration shall be certified by PCA.

4.3.1.7 Maintenance task which may require fault simulation (*see* **6.2.2** and **6.2.3**) shall require that the item be checked for normal operation prior to failure simulation and after completion of the specified maintenance task. When a failure is simulated, it will be the responsibility of the test team to select the maintenance task, the failure to be simulated and the failure mode and to verify that the degree of failure is representative of the maintenance task to be demonstrated. The work area in which parts degradation or failure has been simulated shall contain no obvious evidence other than that normally resulting from the simulated mode of failure. The appearance of the defective parts that are substituted for serviceable parts shall be that of a normally failed part. The technicians shall not witness any fault insertions. Simulation of failures by introduction of faulty parts will not be used when the normal procedures could result in extensive damage to the item being tested. Each defective part is to be installed in the equipment in the same manner as the original part.

4.3.1.8 For maintenance tasks, whose faults have been simulated, the presence of necessary spares, tools, test and support equipment or technical publications shall not assist in faulty isolation of prematurely identifying the work to be done. Such items shall be covered or otherwise kept out of sight from the technician. However, simulated discrepency data shall be made available, if applicable.

4.3.1.9 Maintenance personnel performing maintenance tasks for the demonstration shall be those named in the contract by the procurement agency with the exception that the manufacturer's personnel will perform those tasks specified to be performed by them during the operational service use (*see* **4.3.1.2**). Technicians shall have received the training and be of the equivalent skill level as specified in the standard personnel resource documentation for the specified level of maintenance. Exception to the training and skill level requirements may be made for specified tasks which will be performed by the manufacturer's personnel during operational service use.

4.3.1.10 Each maintenance task will be documented by personnel designated by the test team. The total time measured for a technician to perform each maintenance task shall be recorded and will include the time to perform each element of maintenance time. Each element will be documented separately. The total delay time for each maintenance task shall be documented. The test plan and procedures shall include delay time rules.

4.3.1.11 The time required to obtain support items (appropriate test and support equipment, tools, spare parts, technical publications, etc) from the defined work centre area shall be recorded. This time shall not, however, be chargeable as maintenance task time for the item being demonstrated unless this time is controlled or influenced by the design of the item being demonstrated.

4.3.1.12 Items to be furnished by the manufacturer shall be provided in the type, quality and quantity required for planned operation requirements scaled to the demonstration and evaluation requirements prior to the start of the phase being performed. Items to be furnished by the procurement agency shall be identified and requested by the manufacturer in time to be available prior to the start of the phase being performed.

4.4 Evaluation (Phase III)

4.4.1 The object of evaluation (Phase III) is to evaluate the impact of the actual operational, maintenance and support environment on the maintainability parameters of the system and correction of deficiencies exhibited during Phase II and to demonstrate depot level maintenance tasks when applicable. A maintainability evaluation will be managed and conducted by the procurement agency during operational test and evaluation (OT and E) as part of the total system evaluation. To assure acceptability of recorded data and resultant analysis, the manufacturer shall participate in Phase III to the extent described in **7** or as otherwise provided. The same conditions as outlined for Phase II (*see* **4.3**) shall apply except as given in **4.4.1.1** to **4.4.1.5**.

4.4.1.1 All evaluation items shall be production or production equivalent models.

4.4.1.2 The evaluation shall be conducted in the actual operational and maintenance environment unless otherwise directed by the procurement agency.

4.4.1.3 All maintenance tasks will be accomplished by personnel of the inspection authority stated in the contract by the procurement agency except that the personnel of the manufacturer will perform those tasks specified to be performed by them during operational service use.

4.4.1.4 Depot level maintenance tasks shall be demonstrated and the data collected applied to the maintainability demonstration and evaluation.

4.4.1.5 Maintenance tasks to be evaluated shall be those resulting directly from the incidental to actual operation and maintenance. These tasks shall be supplemented by fault simulation only to evaluate specific tasks or special tasks (*see* **6.2.3**) that do not occur by chance during the evaluation phase.

5. MAINTAINABILITY VERIFICATION/DEMONSTRATION/EVALUATION PLAN

5.1 The maintainability verification/demonstration/evaluation plan which is designated as maintainability test plan hereafter shall form a part of the integrated support plan when an integrated support plan is required. The maintainability test plan shall be prepared and submitted as part of the manufacturer's proposal and progressively updated as design, development and fabrication proceed. It shall be available for in process review by the procurement agency. Those portions of the total maintainability test plan applicable to specific phases (verification, demonstration and evaluation) shall be submitted to the procurement agency for approval prior to its implementation and not later than the date specified by the contract. The plan shall be totally responsive to the qualitative and quantitative requirements and supplemental information contained in the procurement documents and to the maintainability programme plan required by IS : 9692 (Part 3)-1981*. The supplemental information shall include, but not to be limited to, maintenance concept, maintenance environment, skill levels of personnel, level(s) of maintenance to be demonstrated and modes of operation of the test including configuration and omissions. Coordination of the maintainability verification, demonstration and evaluation with other required demonstrations shall be accomplished whenever possible to avoid unnecessary duplication of effort. The environment and procedures shall represent, as closely as possible, those which can be expected in the intended operational use of the item.

5.2 The maintainability test plan prepared by the manufacturer in accordance with the Contract Data Requirement List (CDRL) shall include the following sections, as a minimum, identified with each of the three phases unless otherwise specified. Certain sections cover material subject to other, more specific, contractual requirements and may be included in the maintainability test plan as they are prepared in response thereto. They are included to ensure adequate attention and continuity.

5.2.1 *Background Information* — This shall include a description of the following:

a) Quantitative and qualitative maintainability requirements,
b) Maintenance concept,
c) Maintenance environment,
d) Level(s) of maintenance,
e) Sites,
f) Facilities' requirement,
g) Participating agencies,
h) Mode(s) of operation of the items including configuration and mission requirements,
j) Items subject to verification, demonstration and evaluation, and
k) Contractual data required for completion of the verification/demonstration/evaluation.

5.2.2 *Item Interfaces* — A description of the adequacy or inadequacies of the item support elements and an estimate of their effect on the item maintainability. These elements shall include the following:

a) Maintenance planning;
b) Support and test equipment;
c) Supply support;

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*Guide on maintainability of equipment: Part 3 Maintainability programme.

d) Transportation, handling and storage;
e) Techincal data;
f) Facilities; and
g) Personnel and training.

5.2.3 *Test Team* — This shall include a description of the following:

a) Organization;
b) Degree of manufacturer and procurement agency participation including managerial, technical, maintenance and operation personnel;
c) Assignment of specific responsibilities; and
d) Qualifications, quantity, sources, training and indoctrination requirements for the test team personnel.

5.2.4 *Support Material* — This shall include a description of the following:

a) Support equipment,
b) Tools and test equipment,
c) Technical manuals,
d) Spares and consumables,
e) Safety equipment, and
f) Calibration equipment.

5.2.5 *Preparation Stage* — This shall include a description of and schedule for the following:

a) Organization and assembly of the test team;
b) Training of personnel;
c) Preparation of facilities; and
d) Availability, assembly, checkout and preliminary validation of support material.

5.2.6 *Verification/Demonstration/Evaluation Stage* — This shall include a description of the following:

a) Test objectives;
b) Schedule of tests;
c) Procedure for selection of maintenance tasks when faults are simulated (*see* **6.2.2**);
d) Identification of special maintenance tasks (*see* **6.2.3**);
e) Test method including accept/reject decision criteria, risk, etc;

f) Data acquisition method;

g) Data analysis methods and procedures;

h) Specific data elements;

j) Units of measurements;

k) Type and schedule of reports;

m) Schedule of maintenance task accomplishment such as time change compliance tasks, inspection, lubrication and turn around tasks; and

n) The maintenance tasks other than those listed in **5.2.6**(m) to be verified, demonstrated and evaluated. These tasks may be prepared and submitted in a reference document.

5.2.7 *Retest Stage* — A provisional schedule for special or repeat tests to investigate deficiencies or trouble areas. Deficiencies shall be corrected in any item which has failed to meet the acceptance criteria. The corrected portions of the item and any other portions of the item affected by the correction shall be retested during this stage. The maintenance tasks to be demonstrated shall be as designated by the procurement agency.

6. TEST PROCEDURES

6.1 General — In designing the maintainability test procedures, both qualitative and quantitative requirements shall be verified, demonstrated and evaluated. Unless otherwise specified in the contract, qualitative maintainability requirements shall be verified, demonstrated and evaluated using the check lists prepared by the manufacturer. These check lists, to be approved by the procurement agency, will permit observations, analysis and identification of maintainability characteristics incorporated or omitted. Quantitative requirements shall be verified, demonstrated and evaluated by actual demonstration of maintenance tasks.

6.2 Maintenance Task Generation — All maintenance tasks shall be performed at the maintenance level approved by the procurement agency and in accordance with the approved maintenance plan. Maintenance tasks, both corrective and preventive, shall be generated by the following methods as identified in the final approved maintainability verification, demonstration and evaluation plan.

6.2.1 Actual operation of the item in the specified test, operational and maintenance environment. This method is preferred, provided that assurance can be given that sufficient number of maintenance tasks will occur during the test period to satisfy the minimum sample requirements of the test methods employed (*see* Appendix A).

6.2.2 Fault simulation by introduction of faulty parts, deliberate misalignment, open leads, shorted paths, etc. A maintenance task sampling plan shall be prepared by the manufacturer in accordance with the procedure described in Appendix B or as directed by the procurement agency for approval by the latter. The actual task selection, by the test team, shall not be accomplished until immediately prior to the demonstration.

6.2.3 ' Special ' maintenance tasks which require unique skills, equipment, test method, etc, will be selected by the procurement agency. The method of demonstrating these tasks will be specified by the procurement agency.

6.3 Turnaround Tasks — Tasks comprising turnaround shall be demonstrated. These tasks shall be determined from the planned operational use of the item.

6.4 Test Method — Statistical test methods and criteria for deciding whether specified maintainability requirements have been met are described in Appendix A. Guidance and selection and application of test methods is included with each selection of the test method shall be from Appendix A subject to procurement agency approval or as otherwise specified.

7. ADMINISTRATION

7.1 General — The following procedures shall be followed in the administration of the verification, demonstration and evaluation of the maintainability of the item.

7.2 Test Team Responsibility — The procurement agency's/manufacturer's verification, demonstration and evaluation team(s) for each of the three applicable phases shall be empowered to make decisions for their respective organizations. Each member of the team may have advisers from his organization who are knowledgeable in the various aspects of the demonstration and the requirements of the verification/demonstration/evaluation plan. The responsibilities of the team are in accordance with the manufacturer's approved maintainability verification/demonstration/evaluation plan and shall include, but not limited to the following:

a) To maintain surveillance over maintenance and inspection operation. Any apparent discrepencies in maintenance task accomplishment and documentation observed by any member of the team will be brought to the attention of the remaining test team members within one working day of their occurrence for appropriate action.

b) To evaluate and validate maintenance and operational data to determine applicable man hours, flying hours, operating time, maintenance time, down time, item status, etc.

c) To assure that the demonstration item selected has been adequately prepared in accordance with applicable technical manuals and that no maintenance has been deferred that will compromise the successful completion of the next scheduled operation or mission prior to being placed in an operational ready status.

d) To decide if resulting failures, maintenance time, elapsed down time, maintenance man hours, etc, should be chargeable in cases where operator or maintenance crew error has been committed.

e) To rule on questions of whether or not the verification, demonstration and evaluation plan has been adhered to.

f) To rule on controversial points which may arise that are not specifically covered by applicable specifications or other pertinent documentation. To determine those matters which require contractual interpretation or resolution by the appropriate decision making authority of the procurement agency and by the manufacturer's organization. For these matters, the test team majority and minority statements shall be submitted to the procurement agency and manufacturer's representative for resolution.

g) To prepare and submit demonstration status reports to the procurement agency and the manufacturer.

h) To analyse data and determine the extent of achievement of specified maintainability requirements.

j) To prepare and submit final results of each of the phases to the procurement agency and the manufacturer within the time period indicated in the approved test plan.

k) To assure that the following conditions have been fulfilled prior to the start of Phase II and Phase III and that a letter has been sent to the procurement agency, which, so attests:

    i) Each test item complies with the established configuration or that all deviations reported have been accepted by the procurement agency. It shall be the responsibility of the manufacturer to report all deviations from the approved configuration.

    ii) All required technical manuals have been updated as necessary.

    iii) The support resources are available in the type and quantity specified in the verification, demonstration and evaluation plan.

    iv) All operator or maintenance crew personnel are properly trained and meet established skill level requirements.

    v) All records of approved changes in personnel requirements, operating and maintenance manuals, data handling procedures and analysis techniques have been incorporated in the final revision of the verification, demonstration and evaluation plan.

7.3 Test Director — An individual, designated by the procurement agency as test director, shall decide in all cases of deadlock between the members of the team (subject to contract negotiations where contractual obligations are in question).

7.4 Instrumentation Failures — Any failures of test instrumentation used to measure the demonstration item for test purposes or failures induced by such test instrumentation installation or operation and all associated maintenance shall not be chargeable.

7.5 Maintenance Due to Secondary Failures — If any secondary failures result from a chargeable primary failure, the total resultant maintenance time to restore the items shall be chargeable as a single maintenance task, except when the secondary failure results from the method used to simulate a fault rather than from the fault itself. If the reason for the secondary failure is removed (corrected), the time charge for the secondary failure shall be deleted.

7.6 Inadequate Technical Manuals or Support Equipment — If in the accomplishment of a maintenance task, a technician finds the applicable technical manuals or support equipment to be inadequate, these instances shall be brought to the attention of the test team and, if the inadequacy is verified, this portion of the demonstration shall be terminated and times measured shall not be chargeable. Action shall be taken to correct the inadequacies of the technical manuals or support equipment, after which the same maintenance task shall be repeated.

7.7 Cautions — If an item is damaged or maintenance errors are induced by the item design complexity, by poor design practice or by following improper procedures that allow improper maintenance (for example, interchangeability of connectors) without proper cautions in the technical manuals, the failure and resultant maintenance times shall be chargeable. Action shall be taken to correct the improper procedures or deficiencies and the corrective action verified. When this action is completed, the maintenance time saved shall be deleted.

7.8 Personnel Number and Skill — Each task shall be performed by the prescribed number of personnel with the prescribed speciality codes and skills. If personnel are required on an intermittent or sequenced basis, the man hours assessed against the maintenance task will include the required standby time only if the standby time is of a type or duration which prevents standby personnel from performing other productive tasks.

7.9 Cannibalisation — The maintenance associated with the removal or reinstallation of the item or support equipment assemblies and/or components for cannibalisation purposes shall not be chargeable unless the deficiency can be directly related to lack of manufacturer recommendations for proper level of support spares or expendables. If the manufacturer takes action to correct the deficiency, the time charged shall be deleted.

7.10 Availability — An item shall be considered in an operationally available or operationally ready status (for aircraft) if it is capable of performing in accordance with the item's specification or capable of performing the next scheduled assigned mission.

7.11 Maintenance Inspection — The look portion of any inspection such as pre-flight, post-flight, or phase of a phased inspection shall be considered a separate preventive maintenance task. Each fix of the portion of an inspection shall be considered a separate corrective maintenance task.

8. GFE/GFAE ITEMS

8.1 For Government Furnished Equipment (GFE) and Government Furnished Aeronautical Equipment (GFAE) items, the manufacturer is responsible for determining the GFE/GFAE maintainability characteristics and values required for his Configuration Item (CI) and for assuring that the GFE/GFAE maintainability characteristics and values are not degraded unless compensated for by the demonstrated characteristics and values for other Manufacturer Furnished Equipment (MFE) or GFE/GFAE. The Government will furnish data on known or estimated values of GFE/GFAE reliability and maintainability which shall be used, as applicable, in manufacturer's judgement. The manufacturer is responsible for estimating and demonstrating the maintainability requirements of the entire CI.

9. DATA COLLECTION

9.1 The data collection system used in Phase I and data elements collected shall meet the needs of the objectives of Phase I. In addition, the data system and data elements shall be compatible with the data system used and data elements collected in Phase II and III. During Phase II and Phase III, the test team shall establish and operate a data centre. All data recorded by the test team shall be made available to the manufacturer through the data centre. The test team shall utilise the data system specified by the procurement agency to record all mission debriefing, failure and maintenance data. The manufacturer shall describe maintenance tasks in a manner which will allow proper identification within the services maintenance data collection system that a particular task has occurred, for example, when using the System Effectiveness Data System (SEDS), a maintenance task description shall contain a work unit code. How Malfunctioned and Action Taken Code which uniquely identify that task. Supplementary data collection may be incorporated if approved by the procurement agency. For those items for which the manufacturer has depot level repair responsibilities, he shall be responsible for preparation, accuracy and feedback of the depot level verification, demonstration and evaluation maintenance data for all depot repairables generated. All depot level data elements collected shall be compatible with the data elements collected and recorded at the organisational and intermediate maintenance levels. All direct maintenance down time or man hours, as applicable, which is not specifically determined to be non-chargeable shall be included in the demonstration data and in the calculated quantitative value which determines compliance or non-compliance. Maintenance which might not be chargeable could result from such causes as follows:

a) Maintenance and operational errors not chargeable to technical manuals, manufacturer furnished training or faulty design.

b) Miscellaneous tasks such as keeping of records, taxiing and towing of aircraft to or from an area other than assigned work centre area.

c) Repair of accident damage.

d) Documented delay down time (supply or administrative) which is clearly outside the responsibility of the manufacturer.

e) Modification tasks.

f) Maintenance of test instrumentation exclusive of normal configuration.

g) Maintenance time accountable to test instrumentation installations (other than normal configuration) accrued during maintenance task performance.

10. MAINTAINABILITY PARAMETER CALCULATIONS

10.1 All data acceptable to the team and generated by the demonstration shall be used in calculating the maintainability parameters. The following are typical maintainability parameters which may be stated in the specifications:

a) Mean-time-to-repair (MTTR),

b) Manhour rate,

c) Critical maintenance time or manhours, and

d) Critical percentile and chargeable maintenance down time (a parameter for demonstration of availability).

Appendix A provides methods for calculating these values and the criteria for determining whether the requirements have been achieved. Other methods of calculation tailored to a specific procurement may be provided/approved by the procurement agency.

11. MAINTAINABILITY VERIFICATION/DEMONSTRATION/ EVALUATION REPORTS

11.1 A final report shall be submitted by the test team, after each phase, to the procurement agency in accordance with the schedule incorporated in the verification/demonstration/evaluation plan and the data requirements as per Manufacturer Data Requirements List. The procurement agency may require interim reports where additional detail or extended test durations may be involved. The final report shall include, as a minimum, the following:

a) Summary of a data collected and location of data file;
b) Factors which influence the data;
c) Analysis of the data;
d) Results of the phase and certification that the specified objectives and requirements have or have not been met;
e) Assessment of the integrated logistic support factors, such as technical manuals, personnel, tools and test equipments, support equipment, maintenance concept and provisioning for their effect on quantitative and qualitative demonstration maintainability parameters;
f) Deficiencies;
g) Recommendations to correct deficiencies and for suggested improvements; and
h) Results of retest (if applicable) to be submitted as a supplement to the final report.

12. ORDERING DATA

12.1 The selected data requirements in support of this standard shall be reflected in the Manufacturer Data Requirements List attached to the request for Proposal, Invitation for Bid or the Contract, as appropriate. The following information shall be included in the applicable contractual documents:

a) Phases applicable to the procurement;
b) Dates for submission of the test plan and test procedures for each phase;
c) Type of personnel (Government or manufacturer who will operate and maintain the item for maintainability demonstration);
d) Dates for submission of the final, interim and supplemental (if required) reports for each phase;
e) Data collection system; and
f) Specification requirements and test methods (*see* Appendix A).

APPENDIX A

[*Clauses* 6.2.1, 6.4, 10.1, 12.1(f), B-3.1 *and* B-4.2.10]

TEST METHODS AND DATA ANALYSIS

A-1. OBJECT

A-1.1 The object of this appendix is to describe test methods and criteria for demonstrating the achievement of specified quantitative maintainability requirements.

A-2. APPLICATION

A-2.1 The various methods specified in this appendix are tabulated in Table 1. This table summarises the major characteristics of each test method and the quantitative requirements which shall be specified for each test method. The data analysis method included with each test method provides the decision criteria for acceptance or rejection of the item being demonstrated.

TABLE 1 TEST METHODS

TEST METHOD	TEST INDEX	ASSUMED DISTRIBUTION	SAMPLE SIZE	SAMPLE SELECTION	SPECIFICATION REQUIREMENT
(1)	(2)	(3)	(4)	(5)	(6)
1-A	Mean	Log normal. Prior knowledge of variance	*See* Test Method	Natural occurring failures or Appendix B	H_0, H_1, α, β
1-B	,,	None. Prior knowledge of variance	,,	,,	,,
2.	Critical percentile	Log normal. Prior knowledge of variance	,,	,,	,,
3.	Critical maintenance time or manhours	None	,,	,,	,,
4.	Median	A specific variable log normal	20	,,	ERT

(*Continued*)

TABLE 1 TEST METHODS — *Contd*

TEST METHOD (1)	TEST INDEX (2)	ASSUMED DISTRIBUTION (3)	SAMPLE SIZE (4)	SAMPLE SELECTION (5)	SPECIFICATION REQUIREMENT (6)
5.	Chargeable maintenance down-time/flight†	None	*See* Test Method	Natural occurring failures	ORR or A $\frac{\text{NCMDT, NOF}}{\text{NOF}}$ $\frac{\text{DDT}}{\text{NOF}} \cdot \alpha, \beta^*$
6.	Manhour rate‡	None	,,	,,	Manhour rate, $\triangle$MR
7.	Manhour rate§	None	,,	Natural occurring failures or Appendix B	μ_R, α^*
8.	a) Mean and percentile	a) Log normal	,,	Natural occurring or simple random sampling	a) Mean, M_{max}
	b) Dual percentile	b) None			b) Dual percentile
9.	a) Mean (corrective task time, preventive maintenance time, down-time)	None	30 *Min*	Natural occurring or Appendix B	a) μ_c, μ_{pm} $\mu_{p/c}$*
	b) M_{max} (90 or 95 percentile)				b) M_{max_c}
10.	a) Median (corrective task time, preventive maintenance task time)	None	50 *Min*	Natural occurring or Appendix B	a) $\tilde{M}_{ct}$, $\tilde{M}_{dt}$*
	b) M_{max} (95 percentile) corrective maintenance task time preventive maintenance task time				b) M_{max_c}, $M_{max_{pm}}$

(*Continued*)

TABLE 1 TEST METHODS — *Contd*

TEST METHOD (1)	TEST INDEX (2)	ASSUMED DISTRIBUTION (3)	SAMPLE SIZE (4)	SAMPLE SELECTION (5)	SPECIFICATION REQUIREMENT (6)
11.	a) Mean (preventive maintenance task time)	None	All possible tasks	All	a) μpm*
	b) Mmax (preventive maintenance task time, at any percentile)				b) $M\max_{pm}$

*See **A-6**, for definitions of the symbols.

†Test Method 5 is an indirect method for demonstrating Operational Ready Rate (ORR) or Availability (A).

‡Test Method 6 is intended for use with aeronautical systems and sub-systems.

§Test Method 7 is intended for use with ground electronic systems where it may be necessary to simulate faults.

A-3. SAMPLE SIZE

A-3.1 Each of the test plans contained in this appendix includes an equation or other directions for determining a minimum sample size of maintenance tasks. Any departure from the minimum sample size requirement can affect the statistical validity of the test procedures. Some of the test plans in the appendix require a prior estimate of the variance of the distribution of interest for the calculation of sample size. Such prior estimates, subject to the approval of the procurement authority, can be obtained from data on similar equipment provided similarities in maintainability design, skill levels of maintenance personnel, test equipment, manuals and the maintenance environment are considered in the estimation process. Equations for predicting the variance, when prior estimates are not available, should be obtained from appropriate ‘ Maintainability Prediction and Demonstration Techniques ’ manuals, which can be used, provided the information needed for the production is available. The 85th-95th upper confidence bound on the predicted or estimated variance shall be used to ensure preservation of desired risk values. Average observed values of the variance have ranged from $\sigma^2 = 0{\cdot}5$ to $\sigma^2 = 1{\cdot}3$.

A-4. TASK SELECTION

A-4.1 Selection of tasks to be sampled when employing fault simulation will be made in accordance with Appendix B of this standard. The Procuring Agency shall have the option of surveillance over and/or participating in the random selection of tasks comprising the demonstration population (col 11 of Table 3) down to and including the specific faults to be simulated. This shall occur at a specific conference at a time established by the manufacturer, consistent with the Maintainability Programme Plan schedule. In the event that tasks so chosen can result in events detrimental to safety of personnel or property, appropriate redesign action shall take place; in the event that secondary failures result, they will be documented and their impact on item maintainability assessed. A report of such findings shall be made to the procuring agency. Care shall be exercised in selecting and sampling tasks to ensure that a true simple random sample is obtained when sequential tasks are employed. Departures from simple random sampling, such as proportionate stratified sampling, can effect the validity of the test procedures presented herein. However, this effect is considered minimal for the sample size required by the test procedures which are not sequential tests. Simple random sampling shall be used for sequential tests.

A-5. TEST SELECTION

A-5.1 In general, the test index to be demonstrated is the primary consideration in selecting a test procedure. Considerable savings in sample size can be obtained by use of sequential test procedures in preference to fixed sample tests. As a general rule, however, the sequential test should be used only when prior knowledge (for example, from the prediction) indicates that the equipment may be much better (or worse) than the specified values.

A-5.2 The justification for the use of log normal assumption for corrective maintenance times is based on extensive analysis of field data which have shown that the log normal distribution provides a good fit to the data. However, in those cases where it is suspected that the log normal assumption does not hold (for example, equipment with a high degree of built in diagnostics), then a distribution-free method should be employed to ensure preservation of specified risks.

A-6. SYMBOLS

A-6.1 The following symbols and notations are common to the test methods 1 to 4 and 8 to 11 contained in this appendix. The symbols and notations for tests 5 to 7 are explained in their respective test methods.

X = the random variable which denotes the maintenance characteristics of interest.

X can denote corrective maintenance time, preventive maintenance time, fault location time, manhours per maintenance task, etc.

X_1 = the ith observation or value of the random variable X.

n = sample size.

$\overline{X}$ = sample mean.

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} (X_i)$$

$\sigma^2 = \mathrm{E} [(Ln\, X - \theta)^2]$, the true variance of LnX.

$\mu = \mathrm{E} (X)$, the true mean of X.

$d^2 = \mathrm{Var}(X) = \mathrm{E} [(X - \mu)^2]$, the true variance of X.

$\hat{d}^2$ = sample variance of X.

$$\hat{d}^2 = \frac{1}{n-1} \sum_{i=1}^{n} (X_1 - \overline{X^2})$$

$$= \frac{1}{n-1} \left(\sum_{i=1}^{n} X_1^2 - n\overline{X}^2 \right)$$

$\tilde{d}^2$ = prior estimate of the variance of the maintenance time.

X_p = $(l - p)$th percentile of X.

Example: $X_{0\cdot05}$ is 95th percentile of X.

$\tilde{M}$ = $X_{0\cdot5}$, the median of X.

Y = LnX, the natural logarithm of X.

$\overline{Y}$ = sample mean of Y.

$\theta = \mathrm{E} (LnX)$, the true mean of LnX.

$\tilde{\sigma}^2$ = prior estimate of the variance of the logarithm of maintenance times.

s^2 = sample variance of LnX.

Z_p = standardized normal deviate exceeded with probability, p, that is,

$$p = \int_{Z_p}^{\infty} \frac{1}{\sqrt{2\pi}} \, e^{\left(\frac{-Z^2}{2} \right)} d_z$$

Z_x, $Z_{(1-\beta)}$ = standardised normal deviates, exceeded with probabilities α and $(1 - \beta)$ respectively.

α = producer's risk; the probability that the euipment will be rejected when it has a true value equal to the desired value (H_0).

β = consumer's risk; the probability that the equipment will be accepted when it has a true value equal to the maximum tolerance value (H_1).

H_0 = desired value specified in the contract or specification and is expressed as a mean, critical percentile, critical maintenance time.

H_1 = maximum tolerable value (Note: $H_0 < H_1$) when X is a log normally distributed random variable:

$$f(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}} (LnX - \theta)^2,$$

where $0 < x < \infty$

If $Y = LnX$, then the probability density of Y is normal, with mean θ and variance σ^2:

$$Y \sim N(\theta, \sigma^2)$$

X_{ci} = maintenance downtime per corrective maintenance task (of the i^{th} task).

X_{pmi} = maintenance downtime per preventive maintenance task (of the i^{th} task).

n_c = number of corrective maintenance tasks sampled.

n_{pm} = number of preventive maintenance tasks sampled.

ϕ = that value, corresponding to risk, which is obtained from a table of normal distribution for a one-tail test.

f_c = number of expected corrective maintenance tasks occurring during a representative operating time (T).

f_{pm} = number of expected preventive maintenance tasks occurring during a representative operating time (T).

T = item representative operating time period.

D_t = total maintenance downtime in the representative operating time (T).

$\bar{X}_c$, $\bar{X}_{pm}$, $\bar{X}_{p/c}$ = mean downtimes of sample. (Corrective, preventive and combined corrective/preventive maintenance times.)

$M'_{\max_c}$ = sample calculated maximum corrective maintenance downtime.

μ_c = specified mean corrective maintenance time.

μ_{pm} = specified mean preventive maintenance time.

$\mu_{p/c}$ = specified mean maintenance time (taking both corrective and preventive maintenance time into account).

$M_{\max}$ = a requirement levied in terms of a maximum value of a percentile of task times (that is, 95 percent of all corrective task times shall be less than 60 minutes) usually taken as the 90th or 95th percentile.

$M_{\max_c}$ = specified $M_{\max}$ of corrective maintenance downtimes.

$M_{\max_{pm}}$ = specified $M_{\max}$ of preventive maintenance downtimes.

θ_c = E(LnX_c), expected value of the logarithms of corrective maintenance tasks.

$\tilde{M}_{ct}$ = median value of corrective maintenance tasks.

$\tilde{M}_{pm}$ = median value of preventive maintenance tasks.

Properties of the log normal distribution

Mean, $\mu = e^{\left(\phi + \frac{\sigma^2}{2} \right)}$

Variance, $d^2 = e^{(2\phi + \sigma^2)} \times (e^{\sigma^2} - 1)$

Median, $\tilde{M} = e^{\phi}$

Mode $M = e^{(\phi - \sigma^2)}$

(1 − p) th percentile, $X_p = e^{(\phi + Z_p\sigma)}$

Table of standardized normal deviates

P	Z_p
0·01	2·33
0·05	1·65
0·10	1·28
0·15	1·04
0·20	0·84
0·30	0·52

A-7. TEST METHOD 1 — TEST ON THE MEAN

A-7.1 General — This test provides for the demonstration of maintainability when the requirement is stated in terms of both a required mean value (μ_1) and design goal value (μ_0) [or when the requirement is stated in terms of a required mean value (μ_1) and a design goal value (μ_0) is chosen by the manufacturer]. The test plan is subdivided into two basic procedures, identified here as test plan A and test plan B. Test plan A makes use of the log normal assumption for determining the sample size and test plan B does not. Both the tests are fixed sample tests (minimum sample size of 30) which employ the Central Limit Theorem and the asymptotic normality of the sample mean for their development.

A-7.2 Assumptions

A-7.2.1 *Test A* — Maintenance times can be adequately described by a log normal distribution. The variance σ^2 of the logarithms of the maintenance times is known from prior information or reasonably precise estimates can be obtained.

A-7.2.2 *Test B* — No specific assumption concerning the distribution of maintenance times are necessary. The variance d^2 of the maintenance times is known from prior information or reasonably precise estimates can be obtained.

A-7.3 Hypothesis — H_0 : Mean is $= \mu_0$ ...... (1 - 1)

H_1 : Mean is $= \mu_1$, ($\mu_1 > \mu_0$) ...... (1 - 2)

Illustration — $H_0 : \mu_0 = 30$ min

$H_1 : \mu_1 = 45$ min

A-7.4 Sample Size — For a test with producer's risk α and consumer's risk β, the sample size for Test A is given by

$$n = \frac{(\mathcal{Z}_\alpha \mu_0 + \mathcal{Z}_\beta \mu_1)^2}{(\mu_1 - \mu_0)^2} \left(e^{\tilde{\sigma}^2} - 1 \right) \qquad \text{...... (1 - 3)}$$

where $\tilde{\sigma}^2$ is a prior estimate of the variance of the logarithms of maintenance times:

$$n = \left[\frac{\mathcal{Z}_\alpha + \mathcal{Z}_\beta}{\dfrac{\mu_1 - \mu_0}{\tilde{d}}} \right]^2 \qquad \text{...... (1 - 4)}$$

where $\tilde{d}^2$ is a prior estimate of the variance of the maintenance times. $\mathcal{Z}_\alpha$ and $\mathcal{Z}_\beta$ are standardised normal deviates.

A-7.5 Decision Procedure — Obtain a random sample of n maintenance times, X_1, X_2 ....X_n and compute the sample mean

$$\overline{X} = \frac{1}{n} \sum_{i=1}^{n} Xi \qquad \text{...... (1 - 5)}$$

and sample variance

$$\hat{d}^2 = \frac{1}{n-1} \left(\sum_{i=1}^{n} X_i^2 - n\overline{X}^{2} \right) \qquad \text{...... (1 - 6)}$$

Test A : Accept if $\overline{X} \leqslant \mu_o + Z_\alpha \frac{\hat{d}}{\sqrt{n}}$ ...... (1 - 7)

Test B : Accept if $\overline{X} \leqslant \mu_o + Z_\alpha \frac{\hat{d}}{\sqrt{n}}$ ...... (1 - 8)

Reject otherwise.

A-7.6 Discussion — By the central limit theorem, the sample mean $\overline{X}$ is approximately normal for large n with mean E (X) and variance Var ($\overline{X}$). In Test A under the log normal assumption:

$$\text{Var}\ \overline{X} = \frac{d^2}{n}$$

$$\text{where } d^2 = e^{(2\theta + \tilde{\sigma}^2)} \left(e^{\tilde{\sigma}^2} - 1 \right)$$

$$= \mu^2 \left(e^{\tilde{\sigma}^2} - 1 \right)$$

Thus, the sample size can be computed using a prior estimate of $\tilde{\sigma}^2$.

In Test B, a prior estimate of d^2 is assumed to be available to calculate the sample size.

A critical value C is chosen such that

$C = \mu_o + Z_\alpha \sqrt{\text{Var}\ \overline{X}} = \mu_1 - Z_\beta \sqrt{\text{Var}\ \overline{X}}$

If $\mu = \mu_o$, then

$P (\overline{X} > C) = \alpha$ and if $\mu = \mu_1$, then

$P (\overline{X} \leqslant C) = \beta$

A-7.7 Example — It is desired to test the hypothesis that the mean corrective maintenance time is equal to 30 minutes against the alternate hypothesis that the mean is 45 minutes,

$$\alpha = \beta = 0{\cdot}05$$

Solution

$H_0 : \mu_0 = 30$ minutes.
$H_1 : \mu_1 = 45$ minutes.

Test 'A'

Under the log-normal assumption, with prior estimate of $\widetilde{\sigma}^2 = 0{\cdot}6$, the sample size using equation (1 — 3) is

$$n = \frac{[\,1{\cdot}65\,(\,30\,) + 1{\cdot}65\,(\,45\,)\,]^2}{(\,45 - 30\,)^2}\,(\,e^{0\cdot6} - 1\,) = 56.$$

Test 'B'

Under the distribution free case with a prior estimate of $\widetilde{d^2} = 900$, (or $d = 30$), the sample size using equation (1 — 4) is

$$n = \left[\frac{3{\cdot}29}{\left(\dfrac{45 - 30}{30}\right)}\right]^2 = 43$$

A-7.8 OC Curve — The OC Curve for Test B for this example is given in Fig. 3. It gives the probability of acceptance for values of the mean maintenance time from 20 to 60 minutes. The OC Curve for Test A for this example is given in Fig. 2. It gives the probability of acceptance for various values of the mean maintenance time. Thus, if the true value of μ is 40 minutes, then the probability that a demonstration will end in acceptance is 0·21 as seen from Fig. 2.

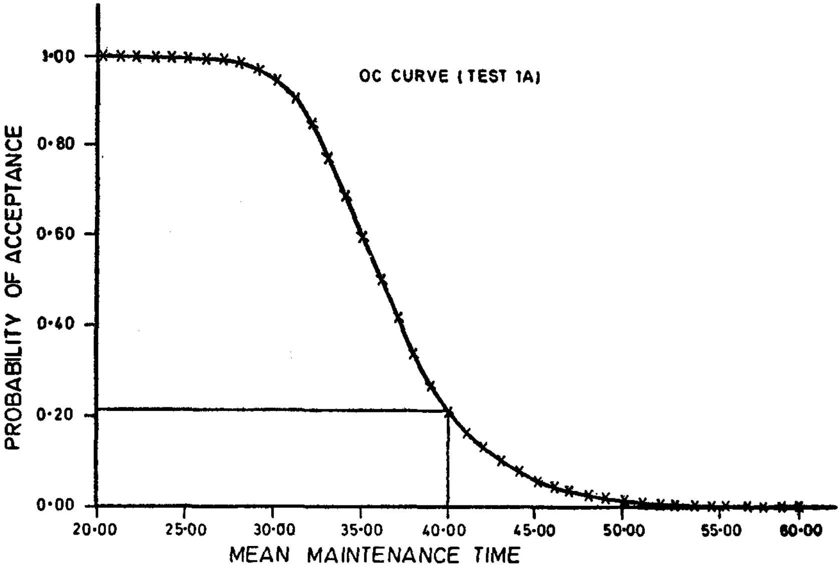


FIG. 2 MEAN

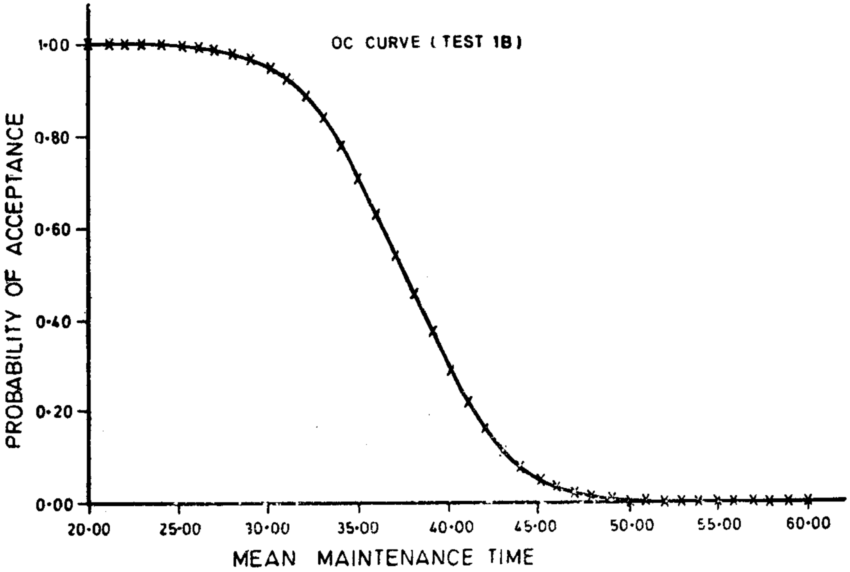


FIG. 3 MEAN

A-8. TEST METHOD 2 — TEST ON CRITICAL PERCENTILE

A-8.1 General — This test provides for the demonstration of maintainability when the requirement is stated in terms of both a required critical percentile value (T_1) and a design goal value (T_0) [or when the requirement is stated in terms of a required percentile value (T_1) and a design goal value (T_0) is chosen by the manufacturer]. If the critical percentile is set at 50 percent, this test becomes a test of the median. The test is a fixed sample size test. The decision criterion is based on the asymptotic normality of the maximum likelihood estimate of the percentile value.

A-8.2 Assumption — Maintenance times can be adequately described by a log-normal distribution. The variance σ^2 of the logarithms of the maintenance times is known from prior information or reasonably precise estimates, can be obtained.

A-8.3 Hypothesis

$$H_0 : (1 - p) \text{ th percentile, } X_p = T_0 \quad \text{or } P[X > T_0] = p \qquad \ldots\ldots (2-1)$$

$$H_1 : (1 - p) \text{ th percentile, } X_p = T_1 \quad \text{or } P[X > T_1] = p, \ (T_1 > T_0). \qquad \ldots\ldots (2-2)$$

Illustration:

H_0 : 95th percentile $= X_p = X_{0\cdot05} = 1\cdot5$ hours $= T_0$
$Ln\ T_0 = 0\cdot405\ 5$
H_1 : 95th percentile $= X_p = X_{0\cdot05} =$ 2 hours $= T_1$
$Ln\ T_1 = 0\cdot693\ 2$.

A-8.4 Sample Size — In order to meet specified α and β risks, the sample size to be used can be obtained from the following formula

$$n = \left(\frac{2 + Z_p^2}{2} \right) \tilde{\sigma}^2 \left(\frac{Z_\alpha + Z_\beta}{Ln\ T_1 - Ln\ T_0} \right)^2 \qquad \ldots\ldots (2 - 3)$$

to be rounded up to the next integer where $\tilde{\sigma}^2$ is a prior estimate of σ^2, the true variance of the logarithms of the maintenance times and Z_p is the standardized normal deviate corresponding to the (1 — p) th percentile.

A-8.5 Decision Procedure — Compute $\overline{Y}$, s^2 and X^* as follows:

$$\overline{Y} = \frac{1}{n} \sum_{i=1}^{n} Ln\ X_i \qquad \ldots\ldots (2 - 4)$$

$$s^2 = \frac{1}{n-1} \left[\sum_{i-1}^{n} (Ln\ X_i)^2 - n\overline{Y}^2 \right] \qquad \ldots\ldots (2 - 5)$$

$$X^* = Ln\ T_0 + Z_\alpha\ S \left[\frac{1}{n} + \frac{Z_p^2}{2(n-1)} \right]^{\frac{1}{2}} \qquad \ldots\ldots (2 - 6)$$

Accept if $\overline{Y} + Z_p\ S \leqslant X^*$ $\qquad \ldots\ldots (2 - 7)$

Reject otherwise.

A-8.6 Discussion — This test is based on the fact that under the log normal assumption, the (1 – p) th percentile value is given by

$$X_p = e^{(\theta + Z_p\sigma)}$$

Taking logarithms,

$$Ln\ X_p = \theta + Z_p\sigma$$

and using maximum likelihood estimates for the normal parameters θ and σ, the (1 – p) th percentile maximum likelihood estimate is

$$Ln\ \hat{X}_p = \overline{Y} + Z_p\ S \sqrt{\frac{n-1}{n}}\ Ln\ X_p$$

which is approximately normal.

To meet the producer's and consumer's risk requirements, a critical value X^* is chosen for the sample estimate of the (1 – p) th percentile X_p. It may be noted that $\overline{Y} = \hat{\theta}$ an estimate for θ.

A-8.7 Example — The following hypothesis are to be tested at

$\alpha = \beta = 0{\cdot}10$

H_0, 95th percentile $= X_{0\cdot05} = 1{\cdot}5$ hours $= T_0$;
$ln\ T_0 = 0{\cdot}405\ 5$

$H_1 =$ 95 percentile $= X_{0\cdot05} =$ 2 hours $= T_1$
$ln\ T_1 = 0{\cdot}693\ 2$

A prior estimate $\tilde{\sigma}^2$ is equal to 1·0 using equation (2 - 3),

$$n = \left[\frac{2 + (1{\cdot}65)^2}{2}\right](1)\left[\frac{(2{\cdot}56)^2}{(ln\ 2{\cdot}0 - ln\ 1{\cdot}5)^2}\right];$$

that is, $n = 187$.

The critical value X^* is given by equation (2 — σ);

$$X^* = ln\ T_0 + Z\alpha\ S\left[\frac{1}{n} + \frac{Z_p^2}{2(n-1)}\right]^{\frac{1}{2}}$$

$$= ln\ 1{\cdot}5 + 1{\cdot}28\ S\left[\frac{1}{187} + \frac{(1{\cdot}65)^2}{372}\right]^{\frac{1}{2}}$$

$$= 0{\cdot}405\ 5 + 0{\cdot}143\ 7\ S$$

A-8.8 OC Curve — The OC Curve for this example (Test Method 2) is given in Fig. 4. It gives the probability of acceptance for various values of the 95th percentile of the maintenance time distribution. If the true value of $X_{3\cdot05}$ is 1·7 hours, then the probability that a demonstration will end in acceptance is 0·57 as seen from Fig. 4.

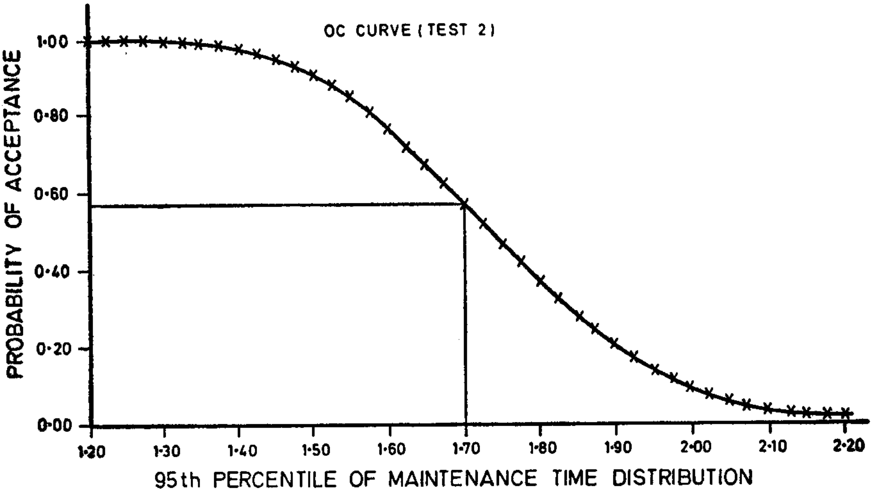


FIG. 4 PERCENTILE

A-9. TEST METHOD 3 — TEST ON CRITICAL MAINTENANCE TIME OR MAN-HOURS

A-9.1 General — This test provides for the demonstration of maintainability when the requirement is specified in terms of both a required critical maintenance time (or critical man-hours) (X_{p1}) and design goal value (X_{po}) [or when the requirement is stated in terms of a required critical maintenance time (X_{p1}) and a design goal value (X_{po}) is chosen by the contractor]. The test is distribution free and is applicable when it is desired to establish controls on a critical upper value on the time or man-hours to perform specific maintenance tasks. In this test, both the null and the alternate hypothesis refer to a fixed time and the percentile varies. It is different from test method 2 where the percentile value remains fixed and the time varies.

A-9.2 Assumptions — No specific assumptions are necessary regarding the distribution of maintenance time or man-hours.

A-9.3 Hypothesis

$$H_0 : T = X_{p_o} \quad (p_1 > p_0) \qquad \text{......(3 - 1)}$$

$$H_1 : T = X_{p1} \quad \text{...........} \qquad \text{......(3 - 2)}$$

for specified α and β:

Illustration:

H_0 : 30 minutes $= X_{0 \cdot 50} =$ 50th percentile (median)

H_1 : 30 minutes $= X_{0 \cdot 75} =$ 25th percentile.

A-9.4 Sample Size and Acceptance Number — The normal approximation to the binomial distribution is employed to find n (sample size) and c (acceptance number) when p_0 is not small. Otherwise, the poisson approximation is employed.

The equations for n and e are as follows:

a) For $0 \cdot 20 \leqslant P_0 \leqslant 0 \cdot 80$. $\quad (P_1 = 1 - Q_1)$

$$n = \left[\frac{Z_\beta \sqrt{P_1 Q_1} + Z_\alpha \sqrt{P_0 Q_0}}{P_1 - P_0} \right]^2 \qquad \text{...... (3 - 3)}$$

Use next higher integer value

$$c = n \left[\frac{Z_\beta P_0 \sqrt{P_1 Q_1} + Z_\alpha P_1 \sqrt{P_0 Q_0}}{Z_\alpha \sqrt{P_0 Q_0} + Z_\beta \sqrt{P_1 Q_1}} \right] \qquad \text{...... (3 - 4)}$$

Use next lower integer value.

b) For $P_0 < 0 \cdot 20$

The values of n and c can be found from the following two equations:

$$\gamma = \sum_{o}^{c} \frac{e^{-nP_0} (nP_0)^{\gamma}}{\gamma!} \geqslant 1 - \alpha \qquad \text{...... (3 - 5)}$$

$$\gamma = \sum_{o}^{c} \frac{e^{-nP_1} (nP_1)^{\gamma}}{\gamma!} \leqslant \beta \qquad \text{...... (3 - 6)}$$

Table 2 provides sampling plans for various α and β risks and ratios P_1/P_0 when $P_0 < 0.20$.

A-9.5 Decision Procedure — In this method, random samples of maintenance times are taken, yielding n observations $X_1, X_2, \ldots\ldots\ldots X$. The number of such observations exceeding the specified time T is counted. The number is called γ. Then,

Accept H_0 if $\gamma \leqslant c$
Reject H_0 if $\gamma > c$

A-9.6 Discussion — In the development of the decision criteria and sample size, equations for the test, the normal or poisson approximation to the binomial distribution is used.

A-9.7 Example — A median value of 30 minutes is considered acceptable whereas if 30 minutes is the 25th percentile, it is considered unacceptable $\alpha = \beta = 0.10$.

H_0 : 30 minutes $= X_{0.50} =$ 50th percentile median
H_1 : 30 minutes $= X_{0.75} =$ 25th percentile

Then, $Z_\alpha = Z_\beta = 1.28$

$P_0 = 0.50$
$P_1 = 0.75$
Using equations (3 - 3) and (3 - 4),

$$n = (1.28)^2 \left[\frac{\sqrt{(0.75)(0.25)} + \sqrt{(0.50)(0.50)}}{(0.25)} \right]^2 \approx 23$$

$$c = 23 \left[\frac{(1.28)\, 0.5 \sqrt{(0.75)(0.25)} + 1.28\, (0.75) \sqrt{(0.50)(0.50)}}{1.28 \sqrt{(0.50)(0.50)} + 1.28 \sqrt{(0.75)(0.25)}} \right] \approx 14$$

A-9.8 OC Curve — The OC Curve for this method and for this example is given in Fig. 5. It gives the probability of acceptance for values of probability p, varying from 0·3 to 1·0. Here, $X_p = (1 - p)$th percentile. Hence, if the true value of the given critical maintenance time is 40th percentile, that is, if the value of p is 0·6, then the probability that a demonstration will end in acceptance is 0·61 as seen from Fig. 5.

TABLE 2 SAMPLING PLANS FOR SPECIFIED P_0, P_1, α and β WHEN P_0 IS SMALL (for example, $P_0 < 0{\cdot}20$)

(*Clause* A-9.4)

$k = \frac{P_1}{P_0}$	$\alpha = 0{\cdot}05$						$\alpha = 0{\cdot}10$						$\alpha = 0{\cdot}20$					
	$\beta = 0{\cdot}05$		$\beta = 0{\cdot}10$		$\beta = 0{\cdot}20$		$\beta = 0{\cdot}05$		$\beta = 0{\cdot}10$		$\beta = 0{\cdot}20$		$\beta = 0{\cdot}05$		$\beta = 0{\cdot}10$		$\beta = 0{\cdot}20$	
	c	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*	*c*	*D*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1·5	66	54·1	54	43·4	39	30·2	51	43·0	40	33·0	29	23·2	36	31·8	27	23·5	17	14·4
2	22	15·7	18	12·4	14	9·25	17	12·8	14	10·3	10	7·02	12	9·91	9	7·29	6	4·73
2·5	13	8·46	10	6·17	8	4·70	10	7·02	8	5·43	6	3·90	7	5·58	5	3·84	3	2·30
3	9	5·43	7	3·98	6	3·29	7	4·66	5	3·15	4	2·43	4	3·09	3	2·30	2	1·54
4	6	3·29	5	2·61	4	1·97	4	2·43	3	1·75	2	1·10	3	2·30	2	1·54	1	0·824
5	4	1·97	3	1·37	3	1·75	3	1·75	2	1·10	2	1·10	2	1·54	1	0·824	1	0·824
10	2	0·818	2	0·818	1	0·353	1	0·532	1	0·532	1	0·824	1	0·825	1	0·824	0	0·227

To find the sample size n, for given P_0, P_1, α, and β, divide the appropriate D value by P_0 and use the greatest integer less than the quotient. Example: $P_0 = 0{\cdot}05, P_1 = 0{\cdot}20$, $\alpha = 0{\cdot}10$, $\beta = 0{\cdot}05$, and $k = \frac{0{\cdot}20}{0{\cdot}05} = 4$. Then $n = \frac{D}{0{\cdot}05} = \frac{2{\cdot}43}{0{\cdot}05} = 48$. The acceptance number is $c = 4$.

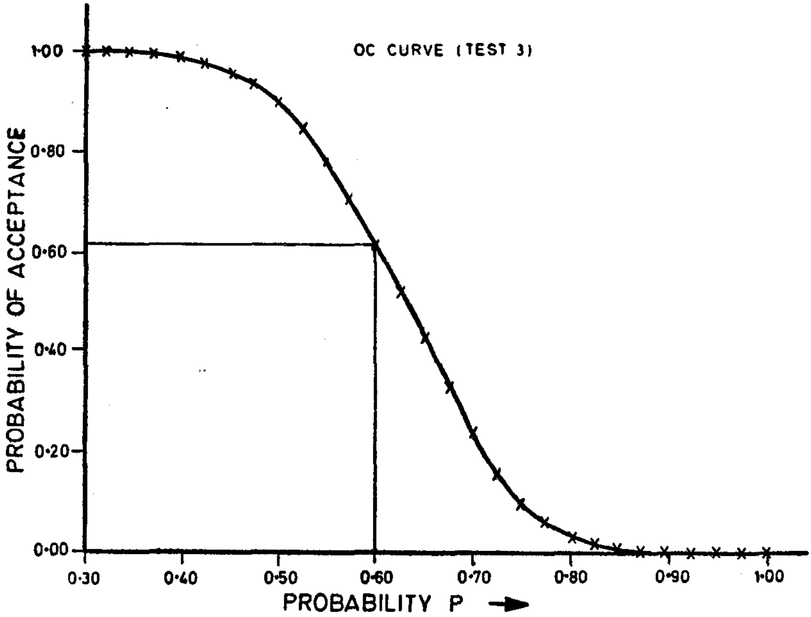


FIG. 5 PROBABILITY. P

A-10. TEST METHOD 4—TEST ON THE MEDIAN (ERT)

A-10.1 General — This test provides for the demonstration of maintainability when the requirement is stated in terms of an equipment repair time (ERT) median which will be specified in the detailed equipment specification.

A-10.2 Assumption — The assumption made in this method is that the underlying distribution of corrective maintenance task times is log normal.

A-10.3 Sample Size — The sample size required is 20. This sample size shall be used to apply the equation given in this test method.

A-10.4 Task Selection and Performance — Sample tasks shall be selected as per Appendix B. The duration of each sample task shall be recorded and used to compute the following statistics:

$$\text{Log } MTTR_G = \frac{1}{n_c} \sum_{i=1}^{n_c} \text{Log } X_{ci} \qquad \ldots\ldots\ldots(4 - 1)$$

$$S = \left[\frac{1}{n_c} \sum_{i=1}^{n_c} (\text{Log } X_{ci})^2 - (\text{Log } MTTR_G)^2\right]^{\frac{1}{2}} \qquad \ldots\ldots\ldots(4 - 2)$$

where $MTTR_G$ = Measured geometric mean time to repair.

It is equivalent to the M_{ct} used in other plans in this specification.

A-10.5 Decision Procedure — The equipment under test will be considered to have met the maintainability requirement (*ERT*) when the measured geometric mean time to repair ($MTTR_G$) and standard deviation (S) as determined in equations (4 - 1) and (4 - 2) satisfy the following expression:

$$\text{Accept if Log } MTTR_G \leqslant \text{Log } ERT + 0{\cdot}397\ (S) \qquad \ldots\ldots(4 - 3)$$

where

Log ERT = logarithm of the equipment repair time,
Log $MTTR_G$ = value determined in accordance with **A-10.4**, and
S = value determined in accordance with **A-10.4**.

A-10.6 Discussion — The value of equipment repair time (*ERT*) to be specified in the detailed equipment specification should be determined using the following expression.

$$ERT \text{ (specified) } = 0{\cdot}37\ ERT_{\max} \qquad \ldots\ldots(4 - 4)$$

where

$ERT_{\max}$ = maximum value of *ERT* that should be accepted no more than 10 percent of the time; and
$0{\cdot}37$ = a value resulting from application of 'student's *t*' operating characteristics that assures a 95 percent probability that an equipment having an acceptable ERT will not be rejected as a result of the maintainability test when the sample size is 20 and assuming a population standard deviation (σ) of 0·55.

A-10.7 Derivation of Criteria

A-10.7.1 The explanation of the derivation of various criteria specified here are for information only.

A-10.7.2 The acceptance criterion, Log $MTTR_G \leqslant$ Log $ERT + 0{\cdot}397(S)$ assures a probability of 0·95 of accepting an equipment or systems as a result of one test when the true geometric mean time to repair is equal to the specified equipment repair time (that is, a probability of 0·05 of rejecting an equipment or systems having true $MTTR_G$ equal to the specified *ERT*). This formula has been derived by using conventional methods for establishing acceptance criteria. The conventional methods for determining acceptance criteria based on the measured mean of a small sample (sample size less than 30) and also when the true standard deviation (σ) of the population can only be estimated is to compare the measured mean with the desired mean using the expression.

$$t = \frac{\overline{X} - \overline{X}_0}{S} \sqrt{n_c - 1}$$

$$S = \sqrt{\frac{\Sigma(X_1 - \overline{X})^2}{n_c}}$$ or the standard deviation of the sample.

where

$\overline{X}$ = sample or measured mean,
$\overline{X}_0$ = specified or desired mean,
n_c = sample size, and
X_1 = value of one measurement of the sample.

A-10.7.3 The decision to accept the product will be made when the test results give a value of t as calculated from the above expression which is numerically less than or equal to a value of t obtained from 'student's t' distribution tables at the established level (such as 0·99, 0·95, 0·90, etc) of acceptance and the appropriate sample size. The 'student's t' distribution tables (for a single tailed area) give a value of $t = 1·729$ at the 0·95 acceptance level when the sample size is 20 (that is, 19 degrees of freedom). The table for single tailed area is used since only values of $MTTR_G$ greater than the specified ERT are critical. An equipment with any value of $MTTR_G$ lower than the specified ERT is acceptable. To apply the expression for t to the maintainability test, the following method should be followed:

Let $\overline{X}_0$ = Log ERT (specified),
$\overline{X}$ = Log $MTTR_G$ (measured),
S = measured standard deviation of the logarithms of the sample of measured repair time, and
N = sample size of 20.

The measured $MTTR_G$ is then compared with the desired ERT by calculating the value of t using the expression:

$$t = \frac{(\text{Log } MTTR_G - \text{Log } ERT)}{S} \sqrt{19}.$$

The equipment under test can be acceptable if the value of t calculated from the expression above is equal to or less than 1·729 (the value of t from the 'student's t' distribution tables at an acceptable level of 0·95 when the sample size is 20). Therefore, the equipment should be accepted when

$$\sqrt{19}\ \frac{(\text{Log } MTTR_G - \text{Log } ERT)}{S} \leqslant 1·729.$$

After re-arranging and simplifying this expression, the acceptance criterion will be

$$\text{Log } MTTR_G - \text{Log } ERT \leqslant \frac{1{\cdot}729}{\sqrt{19}} (S)$$

that is, $\text{Log } MTTR_G \leqslant \text{Log } ERT + 0{\cdot}397\ (S)$.

A-11. TEST METHOD 5 — TEST ON CHARGEABLE MAINTENANCE DOWNTIME PER FLIGHT

A-11.1 General — Due to the relatively small size of the demonstration fleet of aircraft and administrative and operational differences between the fleet and fully operational fleet, operational ready rate or availability can not be demonstrated directly. However, a contractual requirement for chargeable downtime per flight can be derived analytically from an operational requirement of an operational ready rate or availability. This chargeable downtime per flight can be thought of as the allowable time (hours) for performing maintenance provided that the aircraft has levied on it a certain availability or operational readiness requirement. The requirement for chargeable downtime per flight will be established using the procedure outlined in **A-11.4**. Chargeable downtime per flight can then be demonstrated using the procedures given in **A-11.6**.

A-11.2 Definitions — The following definitions are applicable to this method.

A = Availability. A measure of the degree (expressed as a probability) to which an aircraft is in the operable and committable state at the start of the mission when the mission is called for at an unknown (random) point in time. Here, availability is considered synonymous with operational readiness. The aircraft is not considered to be in an operable and committable state when it is being serviced and is undergoing maintenance.

TOT = Total active time in hours.

Active Time = The time during which an aircraft is assigned to an organisation for the purpose of performing the organisational mission. It is the time during which:

a) aircraft is flying or is ready to fly,
b) maintenance is being performed, and
c) maintenance is delayed for supply or administrative reasons.

DUR = Daily utilisation rate. The number of flying hours per day.

AFL = Average flight length. Flying hours per flight.

NOF = Number of flights per day.

DT = Downtime. Time (in hours) during which the aircraft is not ready to commence an assigned mission (for example, flight crew not boarding the aircraft).

CMDT = Chargeable maintenance downtime. Time (in hours) during which maintenance personnel are working on the aircraft except when the only work being done would fall under the non-chargeable maintenance downtime (NCMDT).

NCMDT = Non-chargeable maintenance downtime. Time (in hours) during which an aircraft is not available for immediate flight but the only maintenance being performed is not chargeable. It would include the following:

a) To correct maintenance or operational errors not attributable to technical orders, contractor furnished training or faulty design;

b) Miscellaneous tasks such as keeping of records or taxiing or towing the aircraft to or from other than the work centre area;

c) Repair of accident or battle damage;

d) Modification tasks; and

e) Maintenance caused by test instrumentation.

DDT = Delay downtime. Downtime (in hours) during which maintenance is required but no maintenance is being performed on the aircraft for supply or administration reasons. It includes the following:

a) Supply delay downtime:
   i) Not operationally ready supply (NORS) time, and
   ii) Item obtainment time from other than the work centre area.

b) Administrative delay downtime:
   i) Personal breaks such as coffee or lunch, and
   ii) No maintenance persons available for administrative reasons.

α = Producer's risk. The risk that the producer (contractor) shall take that the hypothesis that a true mean $= M_0$ will be rejected even though it is true. The desirable value of α shall be determined by judgement and agreed upon by the procurement authority and the contractor. All other things being equal, a smaller value of α will require a larger size.

M = Maximum mean chargeable maintenance downtime per flight.

M_0 = Required mean CMDT per flight.

$M - M_0$ = Difference between the maximum mean (M) of the parameter being tested and the specified mean (M_0). This value shall be determined in conjunction with a value for β the consumer's risk. M is a value greater (worse) than the specified mean which the consumer is willing to accept, but only with a small risk or probability (β). If the true mean is, in fact, equal to the value of M selected the hypothesis that the true mean (M_0) will be accepted, although errorneously, is 100 β percent of the time.

β = Consumer's risk. The risk which the consumer is willing to take of accepting the hypothesis that the true mean is equal to M_0 when in fact, the true mean is equal to M. All other things being equal, a smaller value of β will require a larger sample size.

σ = True standard deviation of the parameter (CMDT per flight) being tested. This value, unless it is a specification requirement, will not be known and an estimate of this shall be made. It is assumed that both M and M_0 will have the same value of σ. The contractor's maintainability mathematical model, previous models or previous data may be used for this purpose. All other things being equal, a larger value of σ will require a larger sample size.

A-11.3 Assumptions — This method requires no assumption for the probability distribution of chargeable downtime per flight. This method is valid only if the Central Limit Theorem is applicable, which means, the sample size (number of flights) is large enough for this theorem to be applicable. The sample size shall be atleast 50 but the actual size is to be determined in accordance with **A-11.5**.

A-11.4 Derivation of CMDT per Flight from Availability

A-11.4.1 The requirement for CMDT per flight which will be demonstrated can be determined using the mathematical derivation given below:

$$A = 1 - \frac{\text{CMDT} + \text{NCMDT} + \text{DDT}}{\text{TOT}} \quad \ldots\ldots (5-1)$$

$$\text{A (TOT)} = \text{TOT} - \text{CMDT} - \text{NCMDT} - \text{DDT} \quad \ldots\ldots (5-2)$$

$$\text{CMDT} = \text{TOT} - \text{A (TOT)} - \text{NCMDT} - \text{DDT} \quad \ldots\ldots (5-3)$$

$$\frac{\text{CMDT}}{\text{NOF}} = \frac{\text{TOT} - \text{A (TOT)} - \text{NCMDT} - \text{DDT}}{\text{NOF}} \quad \ldots\ldots (5-4)$$

but

$$\text{NOF} = \frac{\text{TOT (DUR)}}{24 \text{ (AFL)}} \qquad \text{...... (5 - 5)}$$

therefore,

$$\frac{\text{CMDT}}{\text{NOF}} = \frac{24 \text{ (AFL)}}{\text{DUR}} - \frac{\text{A (24) (AFL)}}{\text{DUR}} - \frac{\text{NCMDT}}{\text{NOF}} - \frac{\text{DDT}}{\text{NOF}} \qquad \text{...... (5 - 6)}$$

hence,

$\frac{\text{CMDT}}{\text{NOF}}$ = CMDT per flight, which will be demonstrated.

NOTE 1 — Values for DUR and AFL should be those planned for the aircraft during the operational use.

NOTE 2 — Values for $\frac{\text{NCMDT}}{\text{NOF}}$ and $\frac{\text{DDT}}{\text{NOF}}$ are a function of the operational environment. They will be provided to the contractor in the RFP or, if not, will be provided by him in his proposal. The value for availability or operational ready rate will be provided in the RFP.

A-11.4.2 The following example will show how a requirement for CMDT per flight $\frac{\text{(CMDT)}}{\text{NOF}}$ is derived.

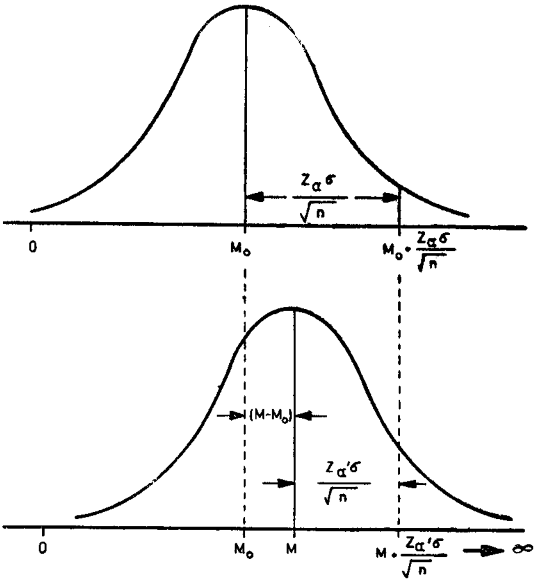
Required A = 0·75
DUR = 2 hours per day
AFL = 4 hours per flight
$\frac{\text{NCMDT}}{\text{NOF}}$ = 0·2 hours per flight
$\frac{\text{DDT}}{\text{NOF}}$ = 1 hour per flight

Therefore

$$\frac{\text{CMDT}}{\text{NOF}} = \frac{24 \text{ (4)}}{2} - \frac{\text{(0·75) (24) (4)}}{2} - 0·2 - 1·0$$
$$= 48 - 36 - 0·2 - 1·0$$
$$= 10·8 \text{ hours per flight.}$$

A-11.5 Sample Size

A-11.5.1 Since the Central Limit Theorem is applied, the expected distribution of the means will be in the form of a normal distribution as in Fig. 6. If the true mean is equal to M_0 and a particular α is desired, the upper distribution (mean of the distribution will be equal to M_0) will apply. It is on this basis that an acceptance rule is generated to the effect that if $\overline{X}$ is found to be equal to or less than the value $M_0 + \frac{Z_\alpha \sigma}{\sqrt{n_c}}$ the item is to be accepted.


$\frac{Z_\alpha \sigma}{\sqrt{n}}$
0
M_o
$M_o + \frac{Z_\alpha \sigma}{\sqrt{n}}$
$(M-M_o)$
$\frac{Z_{\alpha'} \sigma}{\sqrt{n}}$
0
M_o
M
$M + \frac{Z_{\alpha'} \sigma}{\sqrt{n}}$
∞

where $M + \frac{Z_{\alpha'}\sigma}{\sqrt{n}}$ corresponds to the value

$M_O + \frac{Z_\alpha \sigma}{\sqrt{n}}$

FIG. 6 DISTRIBUTION OF MEANS

A-11.5.2 If the true mean is equal to M (which is greater than M_0), the distribution of means will be in the form of a normal distribution with a mean of M as shown in the lower distribution. The value to be used as an acceptance criterion $\left(M_0 + \frac{Z_\alpha \sigma}{\sqrt{n_c}} \right)$ is equal to a value $M + \frac{Z_{\alpha'} \sigma}{\sqrt{n_c}}$ where α' is a new confidence level.

$$\text{Then } M_0 + \frac{Z_\alpha \sigma}{\sqrt{n_c}} = M + \frac{Z_{\alpha'} \sigma}{\sqrt{n_c}} \qquad \ldots\ldots (5-7)$$

$$\text{where } M = M_0 + (M - M_0) \qquad \ldots\ldots (5-8)$$

$$M_0 + \frac{Z_\alpha \sigma}{\sqrt{n_c}} = M_0 + (M - M_0) + \frac{Z_{\alpha'} \sigma}{\sqrt{n_c}} \qquad \ldots\ldots (5-9)$$

or simplifying, the requirement for the sample size (n) is

$$n = \frac{(Z_\alpha - Z_{\alpha'})^2}{\left(\frac{M - M_0}{\sigma}\right)^2} = \frac{[Z_\alpha - Z_{(1-\beta)}]^2}{\left(\frac{M - M_0}{\sigma}\right)^2} \qquad \ldots\ldots (5-10)$$

If this expression should result in n less than 50, then a sample size of 50 shall be used. In this discussion,

α = probability of rejection if true mean equals M,

$1 - \alpha' = \beta$, probability of acceptance, if true mean equals M,

$Z_\alpha \; Z_{(1-\beta)}$ = standardised normal deviates as defined, and

$Z_w = Z_\alpha$ or $Z_{(1-\beta)}$ and $w = \alpha$ or $(1 - \beta)$.

The following table gives the relationship between Z_w and α and β.

Z_w	0·01	0·05	0·1	0·15	0·2	0·3	0·7	0·8	0·85	0·9	0·95	0·99
	2·33	1·65	1·28	1·04	0·84	0·52	−0·52	−0·84	−1·04	−1·28	−1·65	−2·33

Example: Suppose for a requirement of $M_0 = 2{\cdot}0$, the following statistical test parameters were agreed to by the procurement authority and the contractor.

$$\begin{aligned}
\alpha &= 0{\cdot}10 \\
Z_\alpha &= 1{\cdot}28 \\
\beta &= 0{\cdot}10 \\
Z_{(1-\beta)} &= -1{\cdot}28 \\
M - M_0 &= 0{\cdot}30 \\
\sigma &= 1{\cdot}0 \\
\frac{M - M_0}{\sigma} &= 0{\cdot}3;\ \text{using equation (5 - 10)}
\end{aligned}$$

$$n_c = \frac{(1{\cdot}28 + 1{\cdot}28)^2}{(0{\cdot}3)^2} = \frac{(2{\cdot}56)^2}{(0{\cdot}3)^2} = \frac{6{\cdot}57}{0{\cdot}09} = 73.$$

A-11.6 Decision Procedure — The chargeable maintenance downtime (X_i) after each flight will be measured and, at the end of the test, the total chargeable downtime will be divided by the total number of flights to obtain ($\bar{X}$), the sample mean CMDT and the sample standard deviation(s) of CMDT.

$$\bar{X} = \frac{\sum_{i=1}^{\text{NOF}} X_i}{\text{NOF}} \qquad \text{......(5 - 11)}$$

$$S = \sqrt{\sum_{i=1}^{\text{NOF}} \frac{(X_i - \bar{X})^2}{(\text{NOF}) - 1}} = \sqrt{\sum_{i=1}^{\text{NOF}} \frac{X_i^2 - (\text{NOF})\,\bar{X}^2}{(\text{NOF}) - 1}}$$

...... (5 - 12)

$$\text{Accept if } \bar{X} \leqslant M_0 + \frac{Z_\alpha S}{\sqrt{\text{NOF}}} \qquad \text{...... (5 - 13)}$$

$$\text{Reject if } \bar{X} > M_0 + \frac{Z_\alpha S}{\sqrt{\text{NOF}}} \qquad \text{...... (5 - 14)}$$

A-12. TEST METHOD 6 — TEST ON MANHOUR RATE

A-12.1 General

A-12.1.1 This test provides for the demonstration of manhour rate (manhours per flight hour). This test is based on a determination during phase II test operation of the total cumulative chargeable maintenance manhours and the total cumulative demonstration flight hours. The demonstrated manhour rate is equal to

$$\text{Manhour Rate} = \frac{\text{Total Chargeable Maintenance Manhours}}{\text{Total Demonstration Flight Hours}} \qquad \ldots\ldots (6-1)$$

A-12.1.2 If the demonstrated manhour rate is less than or equal to the manhour rate requirement plus a maximum value (ΔMR) by which the demonstrated manhour rate, then the requirement has been met. MR will be provided by the procurement authority as a percentage of the system manhour rate requirement and will be determined based on considerations such as the expected phase II duration and prior experience with similar systems. It is recognised that this demonstration method is non-statistical in nature and does not allow the determination of quantitative producer's and consumer's risk levels. It is for this reason that the ΔMR is provided (in a subjective manner) to minimise the producer's risk.

A-12.1.3 Normally, all maintenance performed by approved maintenance test personnel during phase II and documented in appropriate maintenance reports will be the source of data for identifying chargeable maintenance manhours. The procurement authority may elect to terminate the demonstration prior to phase II completion if sufficient data is collected to project that the requirement will be met.

A-12.1.4 The manhour rate requirement shall pertain to the aircraft configuration provided for in the contract. For phase II flights conducted with a configuration other than this, an appropriate amount of chargeable manhours will be included in calculating the total chargeable manhours. This amount will be based upon the predicted manhour rate associated with the equipment not installed.

A-12.1.5 Care shall be exercised in assuring that the predicted manhour rate pertains to flight time and not equipment operating time. The contractor shall develop appropriate ratios of equipment operating time to flight time.

A-13. TEST METHOD 7 — TEST ON MANHOUR RATE (USING SIMULATED FAULTS)

A-13.1 General — This test provides for demonstrating manhour rate (manhours per operating hour). This test is based on the predicted total failure rate of the equipment used in the formulation of Table 3, Appendix B and also on the total accumulative chargeable maintenance manhours and the total accumulative simulated demonstration operating hours.

The demonstrated manhour rate is equal to

$$\text{Manhour rate} = \frac{\text{Total Chargeable Maintenance Hours}}{\text{Total Operating Time}}$$

$$= \frac{\sum\limits_{i=1}^{n} X_{ci} + (PS)}{T} \qquad \text{...... (7 - 1)}$$

where

X_{ci} = manhours for corrective maintenance task i.

n = number of corrective maintenance tasks sampled, n shall not be less than 30.

MTBF = MTBF of the unit (value used in development of Table 3).

(PS) = estimated average total manhours which would be required for preventive maintenance during a period of operating time equal to n_c (MTBF) hours.

$\sum\limits_{i=1} \frac{X_{ci}}{n_c} = \overline{X}_c$ = average number of corrective maintenance manhours per corrective maintenance task.

T = operating time.

A-13.2 Discussion — When maintenance tasks are simulated as in Table 3.

$T = n$ (MTBF) where $\frac{1}{\text{MTBF}} = \lambda T$ the total failure rate of the equipment under consideration.

$$\frac{\sum\limits_{i=1}^{n} X_{ci} + (PS)}{T} = \frac{\sum\limits_{i=1}^{n} X_{ci} + (PS)}{n\,(\text{MTBF})} = \frac{1}{\text{MTBF}}\left[\overline{X}_c + \frac{(PS)}{n_c}\right] \qquad \text{...... (7 - 2)}$$

All components of (7 - 2) with the exception of $\overline{X}_c$ can be considered constants. $\overline{X}_c$ can be considered a normally distributed variable when n_c is large (due to the Central Limit Theorem) with Variance $= \frac{d^2}{n_c}$.

EQUIPMENT : RADAR XYZ

TABLE 3 STRATIFICATION PROCEDURE

(*Clauses* A-4.1, A-13.1, A-13.2, B-4.2, B-4.2.10, B-4.2.11 *and* B-4.2.12)

MAJOR UNITS	FUNCTIONAL LEVEL OF MAINTENANCE	MAINTENANCE TASK	ESTIMATED MEAN MAINTENANCE TIME	FAILURE RATE MEAN F/10⁶	QTY. OF ITEMS	DUTY CYCLE	TASK GROUPING	TOTAL FAILURE RATE	RELATIVE FREQUENCY OF OCCURRENCE	FIXED SAMPLE Demonstration Population Allocation	FIXED SAMPLE Demonstration Sample Size	VARIABLE SAMPLE CUMULATIVE RANGE
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
			h	h								
Antenna	Antenna	R/R (A)	1·0	105	1	1·0	Group 1 Task A	105	0·177	35	9	0 – 0·176 9
Receiver/ transmitter	IF — A	R/R (A)	0·3	23	1	1·0	Group 2 Task A	108	0·178	A-8	A-2	0·177 0 – 0·345 9
	IF — B	R/R (B)	0·3	21	1	1·0	Group 2 Task B			B-7	B-2	
	Amplifier	R/R (C)	0·4	21	1	1·0	Group 2 Task C			C-7 } 36	C-2 } 9	
	Modulator	R/R (D)	0·4	18	1	1·0	Group 2 Task D			D-6	D-1	
	Power supply	R/R (E)	0·4	23	1	1·0	Group 2 Task E			E-8	E-2	
	Transmitter	R/R (F)	0·5	10	1	1·0	Group 3 Task F	10	0·016	3	1	0·355 0 – 0·370 9
Frequency tracker	Frequency tracker	R/R (A)	0·6	400	1	0·7	Group 4 Task A	280	0·472	94	23	0·37 10 – 0·842 9
		Replace crystals (B)	0·5	20	4	0·7	Group 5 Task B	56	0·094	19	5	0·843 0 – 0·936 9
Radar set-control	Radar set-control	R/R (A)	0·5	35	1	0·8	Group 6 Task A	28	0·047	10	2	0·937 0 – 0·983 9
Drift angle indicator	Drift angle indicator	R/R (A)	0·5	10	1	0·8	Group 7 Task A	8	0·013	3	1	0·984 0 – 1·00
								595	1·00	200	50	

NOTE 1 — R/R = Remove/Replace (includes time to perform each element of maintenance time).

NOTE 2 — This table is for illustration only. It is not intended to represent a complete radar and the entries should not be considered as real data.

NOTE 3 — Delete columns 11 and 12 for sequential test methods.

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If $\overline{X}_c$ is normally distributed, it can be shown that,

$\frac{1}{\text{MTBF}}\left[\overline{X}_c + \frac{PS}{n_c}\right]$ is also normally distributed around the mean of the manpower rate with variance $= \frac{1}{n_c}\left(\frac{d}{\text{MTBF}}\right)^2$ assuming $d = \hat{d}$.

A-13.3 Decision Procedure — If the manhour rate requirement is μ_R,

$$\text{Accept if } \overline{X}_c \leqslant \mu_R\,(\text{MTBF}) = \frac{PS}{n} + Z_\alpha \frac{\hat{d}}{n_c} \qquad \ldots\ldots (7-3)$$

where α denotes procedure's risk.

A-14. TEST METHOD 8 — TEST ON A COMBINED MEAN/PERCENTILE EQUIPMENT

A-14.1 General — This test provides for the demonstration of maintainability when the specification is couched in terms of a dual requirement for the mean and either the 90th or 95th percentile of maintenance times when the distribution of maintenance time is log normal.

A-14.2 Assumptions — For use as a dual mean and 90th or 95th percentile requirement the mean shall be greater than 10 and less than 100 units of time; the ratio of the 90th percentile maximum value to the value of the mean shall be less than two; the ratio of the 95th percentile maximum value to the value of the mean shall be less than three.

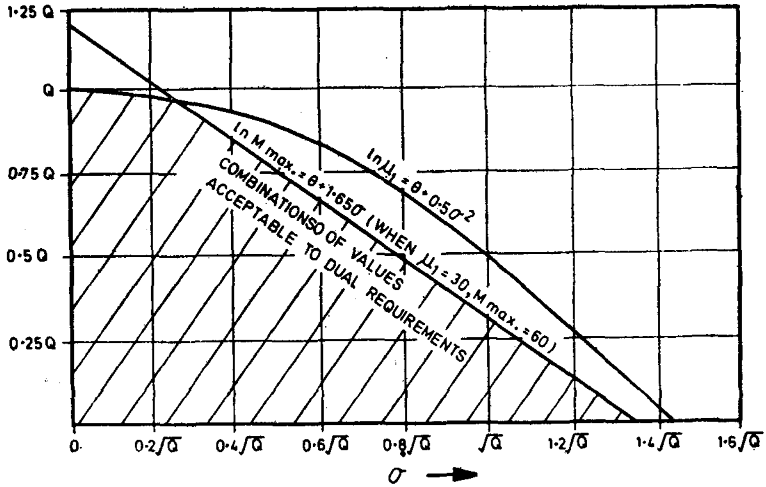
Maximum ratio of percentile to mean

90th Percentile Value	2
95th Percentile Value	3

Distribution assumptions are defined in **A-14.1**.

A-14.3 Discussion — The test method actually demonstrates the 61st percentile value of maintenance time in combination with either the 90th or 95th percentile values of maintenance time rather than the mean value of maintenance time in combination with either the 90th or 95th percentile values of maintenance time. However, because of the particular characteristic of the log normal distribution once a 61st percentile value of maintenance time less than X_1 and a 90th or 95th percentile value less than X_2 has been demonstrated, for all practical purposes a mean value of less than approximately X_1 and a 90th or 95th percentile value less than X_2 have likewise been demonstrated.

A dual requirement on maintainability, assuming a log normal distribution of repair times of a maximum value of the *Mean* in conjunction with either the maximum value of the 90th or 95th percentile of repair time (to be referred to as $M_{\max}$) results in the definition of various combinations of θ's and σ's which are acceptable to the dual requirement. (A complete technical description of a log normal distribution is provided by knowledge of θ and σ, hence, all possible log normal distributions acceptable to the requirements are defined through definition of all possible acceptable values of θ and σ.) *See* Fig. 7 which defines the acceptable combinations of θ and σ for a mean of 30 min and a 95th percentile ($M_{\max}$) of 60 minutes.



let μ_1 = required value of mean (maximum allowable).

let X_{p_1} = maximum value of 95th percentile = $M_{\max}$.

$\ln \mu_1 \geqslant \theta + 0{\cdot}5\sigma^2$

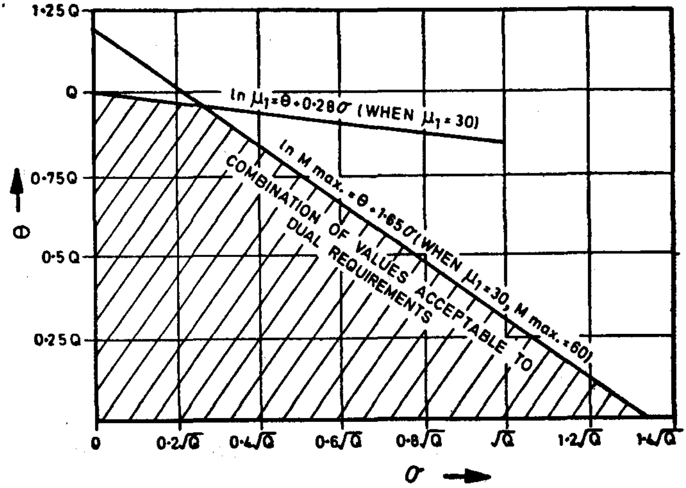
$\ln M \geqslant \theta + 1{\cdot}65\sigma$

define all possible values of θ and σ which are capable of meeting or bettering the requirement (defines the characteristics of all possible lognormal distributions capable of meeting or bettering the requirements).

let $\ln \mu_1 = Q$

FIG. 7 ACCEPTANCE COMBINATION OF Q AND σ FOR $\mu_1 = Q + 0{\cdot}5\,\sigma^2$

For the log normal distribution it is also possible to structure a dual requirement made up of the maximum values of two percentiles (for example, the 61st percentile of repair time shall be a maximum of 30 minutes and the 95th percentile of repair time shall be a maximum of 60 minutes). This dual requirement also results in the definition of various combinations of acceptable values of θ and σ (*see* Fig. 8). If a dual percentile requirement could be structured such that the set of acceptable values of θ and σ defined were almost identical to the set of values of θ and σ defined for a given dual *Mean and percentile* requirement then a demonstration of that *dual percentile requirement* would in reality also demonstrate *the attainment of the dual Mean and $M_{\max}$ requirement.* For this particular instance it has been found that under the assumptions listed above, almost identical acceptable values of θ and σ are provided for a *combined Mean and $M_{\max}$ requirement* and a *combined 61st percentile* where the value of the 61st percentile is taken equal to the specified value of the Mean) and *$M_{\max}$ requirement. See* Fig. 8 which defines the values of θ and σ acceptablet o a dual 61st percentile (where the value of the 61st percentile is taken equal to a *specified mean* of 30 minutes) and 95th percentile, (where the maximum value of the 95th percentile $M_{\max}$, is given as 60 minutes) and Fig. 9 which is the superimposition of Fig. 7 on Fig. 8.



let μ_1 = required value of mean (maximum allowable).

let X_{p1} = maximum value of 95th percentile = $M_{\max}$.

using the required value for the mean as the maximum value of the 61st percentile.

$\ln \mu_1 \geqslant \theta + 0{\cdot}28\sigma$

$\text{tn}\, M_{\max} \geqslant \theta + 1{\cdot}65\sigma$

define all possible values of θ and σ which are capable of meeting the dual percentile requirement.

let $\ln \mu_1 = Q$

FIG. 8 ACCEPTABLE COMBINATION OF Q AND σ FOR $\mu_1 = \theta + 0{\cdot}28\,\sigma$

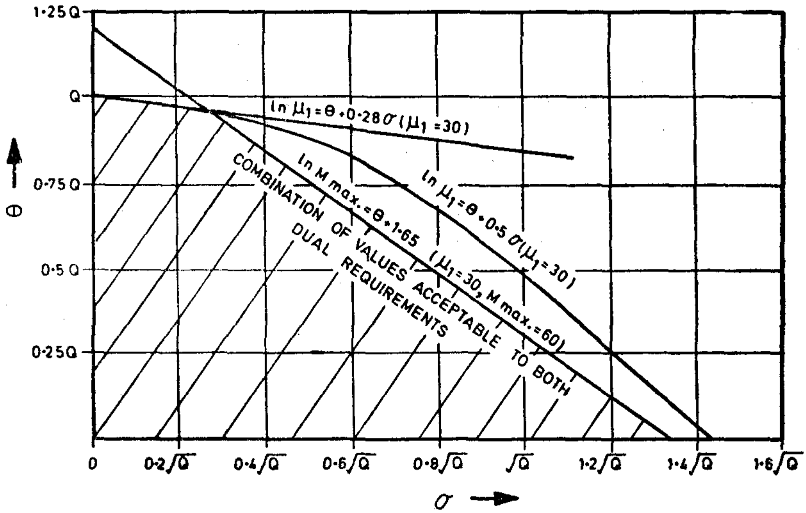


FIG. 9 ACCEPTABLE COMBINATION OF Q AND σ FOR $\mu_1 = 0{\cdot}28\ \sigma$ AND $\mu_1 = Q + 0{\cdot}5\ \sigma^2$

Therefore, tests performed to demonstrate the attainment of both the percentiles in question actually demonstrates the attainment of values of θ and σ which are almost identically acceptable to a dual requirements of the Mean and M_{max}. It follows then that an accept decision relative to both percentiles would also approximately signify an accept decision for a dual Mean and M_{max} requirement.

Since both percentiles can be considered independent for practical purposes, the same samples can be used for demonstrating both percentiles, therefore, if desired the tests may be run simultaneously.

A-14.4 Procedure — Sample tasks shall be selected with respect to the procedure defined for variable sample/sequential tests. The same sample tasks may be used simultaneously in the demonstration of both the Mean and M_{max} requirements. Tables 4, 5 and 6 (which are appropriate to Test Plans A_1, B_1 and B_2, respectively) are based upon the sequential probability ratio test of proportion. They define the accept/reject criteria for the values of the required mean, M_{max} (when defined as the maximum 90th percentile value), M_{max} (when defined as the maximum 95th percentile value), respectively. The number of observations greater than and less than the required values of the Mean and M_{max} shall be cumulated separately and compared to the decision values shown in the tables applicable to the two requirements. When one plan provides an

TABLE 4 PLAN A_1

(*Clause* A-14.4)

Observations Exceeding the Value of the Mean (or 61st percentile value)

# OF TASKS OBSR (n_c)	ACCEPT	REJECT	# OF TASKS OBSR (n_c)	ACCEPT	REJECT
5		5	55	12	↕
6		6	56	13	20
7		↕	57	↕	21
8		6	58	13	↕
9		7	59	14	21
10		↑	60	↑	22
11		↓	61	↓	↕
12	0	7	62	14	22
13	↕	8	63	15	23
14	0	↕	64	↕	↑
15	1	8	65	15	↓
16	↑	9	66	16	23
17	↓	↑	67	↕	24
18	1	↓	68	16	↕
19	2	9	69	17	24
20	↕	10	70	↑	25
21	2	↕	71	↓	↑
22	3	10	72	17	↓
23	↕	11	73	18	25
24	3	↕	74	↕	26
25	4	11	75	18	↕
26	↑	12	76	19	26
27	↓	↑	77	↕	27
28	4	↓	78	19	↕
29	5	12	79	20	27
30	↕	13	80	↑	28
31	5	↕	81	↓	↑
32	6	13	82	20	↓
33	↕	14	83	21	28
34	6	↕	84	↕	29
35	7	14	85	21	↕
36	↑	15	86	22	29
37	↓	↑	87	↑	30
38	7	↓	88	↓	↕
39	8	15	89	22	30
40	↕	16	90	23	31
41	8	↕	91	↕	↑
42	9	16	92	23	↓
43	↑	17	93	24	31
44	↓	↑	94	↕	32
45	9	↓	95	24	↕
46	10	17	96	25	32
47	↕	18	97	↑	33
48	10	↕	98	↓	↑
49	11	18	99	25	↓
50	↕	19	100	26	33
51	11	↕			
52	12	19			
53	↑	20			
54	↓	↕			

TABLE 5 PLAN B_1

(*Clause* A-14.4)

Observations Exceeding M max — 90 Percentile

# of Tasks OBSR (*nc*)	Accept	Reject	# of Tasks OBSR (*nc*)	Accept	Reject
2		2	52		4
3		↑	53		5
4			54		↑
5			55		
6			56		
7			57		
8			58		
9			59		
10			60		
11			61		
12		↓	62		
13		2	63	↓	
14		3	64	1	
15		↑	65	2	
16			66	↑	
17			67		
18			68		
19			69		
20			70		
21			71		↓
22			72		5
23			73		6
24			74		↑
25			75		
26	0		76		
27	↑		77		
28			78		
29			79		
30			80		
31			81		
32		↓	82		
33		3	83	↓	
34		4	84	2	
35		↑	85	3	
36			86	↑	
37			87		
38			88		
39			89		
40			90		
41			91		↓
42			92		6
43			93		7
44	↓		94		↑
45	0		95		
46	1		96		
47	↑		97		
48			98		
49			99	↓	↓
50			100	3	7
51		↓			

TABLE 6 PLAN B_2

(*Clause* A-14.4)

Observations Exceeding Mmax — 95 Percentile

# OF TASKS OBSR (n_c)	ACCEPT	REJECT	# OF TASKS OBSR (n_c)	ACCEPT	REJECT
2		2	52		
3		↑	53		
4			54		
5			55		
6			56		
7			57	0	
8			58	↑	
9			59		
10			60		
11			61		
12			62		
13			63		
14			64		
15			65		
16			66		
17			67		
18			68		↓
19			69		3
20			70		4
21			71		↑
22			72		
23			73		
24			74		
25			75		
26		↓	76		
27		2	77		
28		3	78		
29		↑	79		
30			80		
31			81		
32			82		
33			83		
34			84		
35			85		
36			86		
37			87		
38			88		
39			89		
40			90		
41			91		
42			92		
43			93		
44			94		
45			95		
46			96		
47			97	↓	
48			98	0	
49			99	1	↓
50			100	1	4
51					

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accept decision, attention to that plan shall be discontinued. The second plan shall continue until a decision is reached. The equipment shall be rejected when a decision to reject on either plan has occurred regardless of the status of the other plan. The equipment shall be accepted only when an accept decision has been reached on both plans. If no accept or reject decision has been made after 100 observations, the following rule shall apply:

Plan A_1 — Accept only if 29 or less observations are more than the value of the required Mean.

Plan B_1 — Accept only if 5 or less observations are more than $M_{\max_c}$.

Plan B_2 — Accept only if 2 or less observations are more than $M_{\max_c}$.

It is recognised and accepted that truncation will somewhat modify probability of acceptance characteristics as described in the following section.

A-14.5 The OC Curve — The operating characteristic curve for the test procedure may be determined by mapping the probability of acceptance for various selected points on a diagram of the acceptable and unacceptable regions such as Fig. 10. [Note that any point can be identified uniquely by the coefficient of Q, where $Q = L$ (required mean), on the ordinate and the coefficient of $\sqrt{Q}$ on the abcissa. Let the coefficient of Q be denoted as (C) and the coefficient of $\sqrt{Q}$ be denoted as (K) — for example, point B

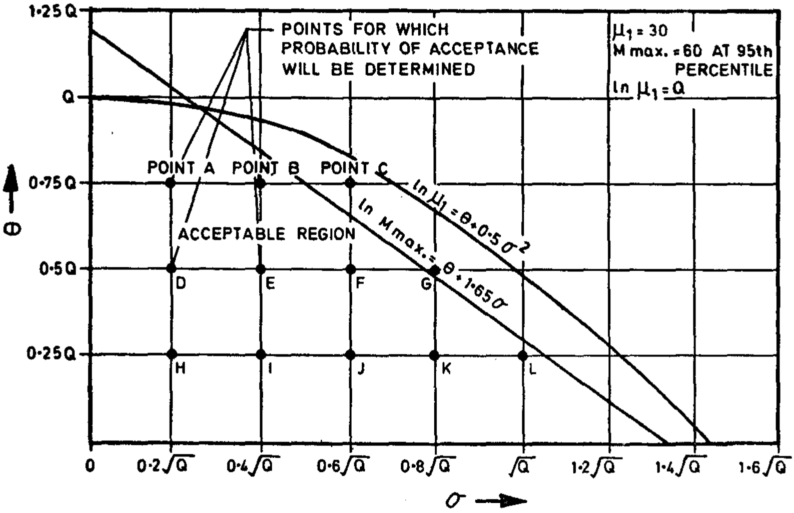

Fig. 10 Probability of Acceptance

on Fig. 10 can be uniquely located at $C = 3/4$, $K = 0{\cdot}4$). Each point is also representative of a particular log normal distribution possessing unique percentiles for the values given for μ_1 (required maximum value for mean) and $M_{\max}$, respectively.]

The probability of acceptance relative to any point is equal to the compound probability of passing the percentile test relative to μ_1 (test A_1) and passing the percentile test relative to $M_{\max}$ (test B_1 or B_2).

Let P_{A1}, P_{B1}, P_{B2} be the probability of passing tests A_1, B_1, B_2 respectively for any given unique combination of θ and σ (a particular point).

P_{A1}, P_{B1}, P_{B2} may be determined by calculating Y_{A1}, Y_{B1}, Y_{B2} from the following equations:

$$Y_{A1} = \frac{\sqrt{Q}\,(1-C)}{K} \quad \ldots\ldots (8\text{-}1)$$

$$Y_{B1} = Y_{B2} = \frac{L_n\, M_{\max} - CQ}{K\sqrt{Q}} \quad \ldots\ldots (8\text{-}2)$$

and entering Fig. 11 (for Test A_1) with the calculated value of Y_{A1} and Fig. 12 (for Test B_1) or Fig. 13 (for Test B_2) with the calculated value of Y_{B1} or Y_{B2}. The corresponding value of probability of acceptance, P_{A1} and P_{B1} or P_{B2} (whichever of the B tests are appropriate) is read *from each* Figure and P_{A1} and the appropriate P_{B1} or P_{B2} values are multiplied. The result of this multiplication is the probability of acceptance of a unit having a particular θ and σ characteristic defined by (C) and (K).

Repeating the above for a number of points as in Fig. 14 defines an operating characteristic map relative to a given dual requirement. Note that probabilities of acceptance always decrease as the point is located upward or to the right and always increase as the point in consideration is located downward or to the left on the figure. Hence, sufficient knowledge of test characteristics can be generated by evaluating relatively few points.

A-15. TEST METHOD 9 — TEST FOR MEAN MAINTENANCE TIME (CORRECTIVE PREVENTIVE COMBINATION OF CORRECTIVE AND PREVENTIVE) AND $M_{\max}$

A-15.1 General — This method is applicable to demonstration of the following indices of maintainability: Mean Corrective Maintenance Time (μ_c), Mean Preventive Maintenance Time (μ_{pm}), Mean Maintenance Time (includes preventive and corrective maintenance actions ($\mu_{p/c}$), and percentile of repair time (M_{max}).

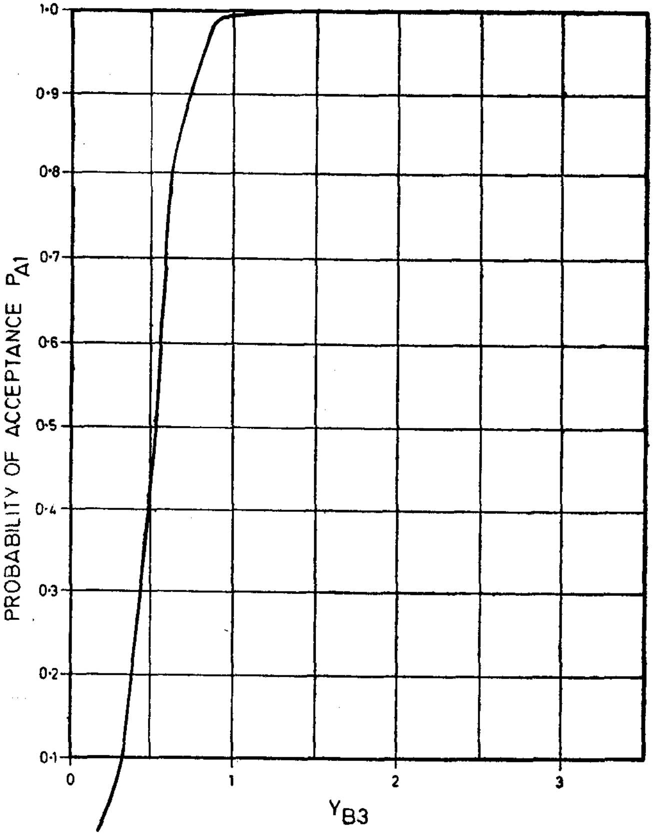

FIG. 11 PROBABILITY OF ACCEPTANCE FOR TEST A_1

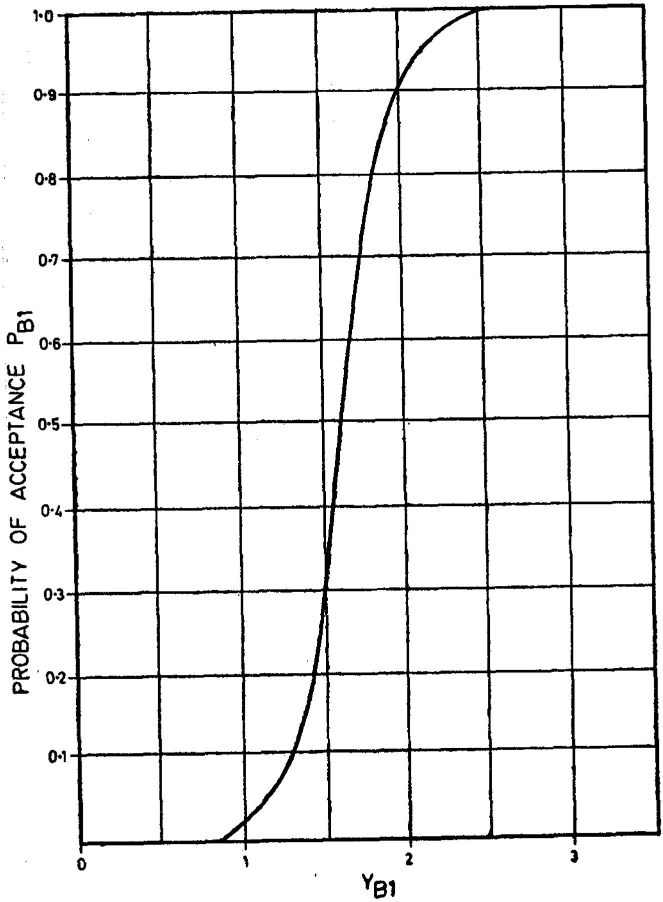

FIG. 12 PROBABILITY OF ACCEPTANCE FOR TEST B_1

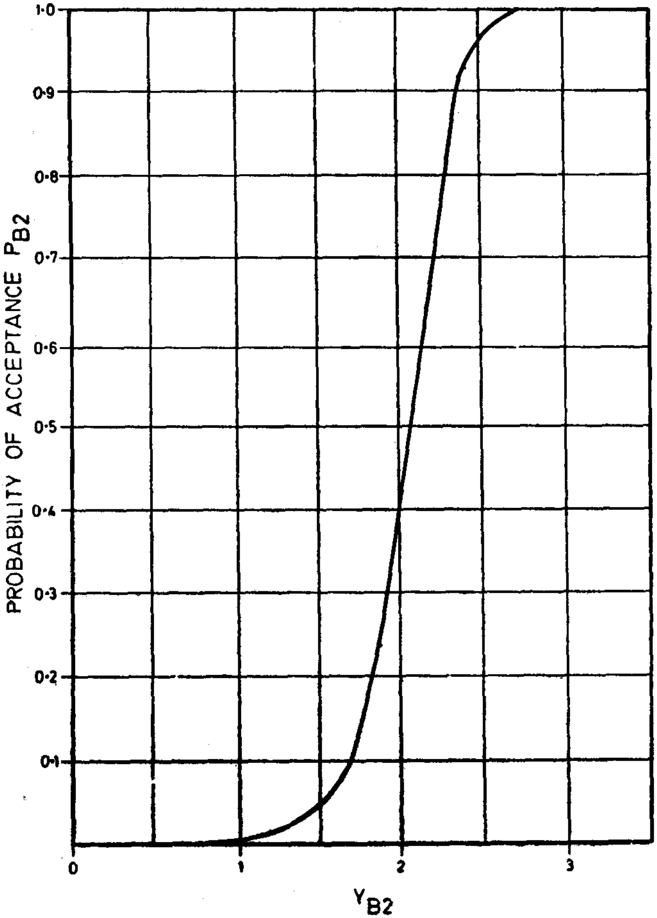

FIG. 13 PROBABILITY OF ACCEPTANCE FOR TEST B_2

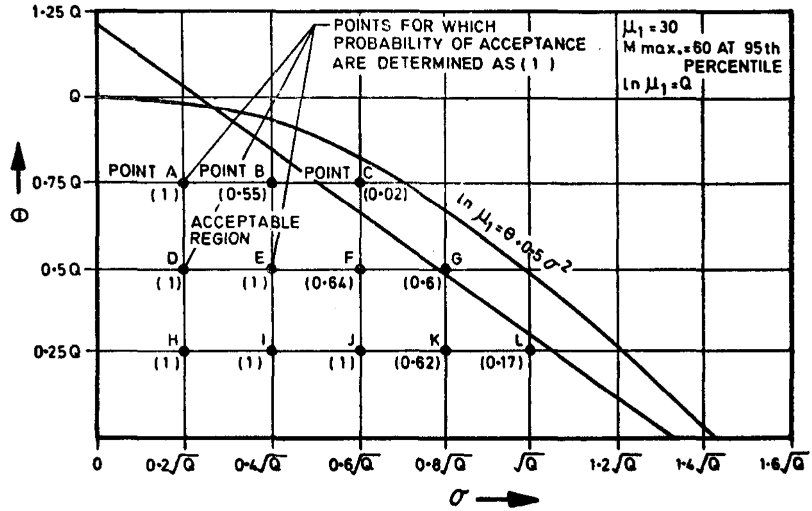

FIG. 14 OPERATING CHARACTERISTIC MAP RELATIVE TO A GIVEN DUAL REQUIREMENT

A-15.2 Conditions of Use — The procedure of this method for demonstration of μ_C, are based on the Central Limit Theorem. No information relative to the variance (d^2) of maintenance times is required. It may therefore be applied whatever the form of the underlying distribution, provided the sample size is adequate. The minimum sample size is set at 30. The actual sample size (if greater than 30 are required) shall be determined for each equipment to be demonstrated, and shall be approved by the procuring agency.

The procedure of this method for demonstrating M_{max} is valid for those cases where the underlying distribution of corrective maintenance task times in log normal.

A-15.3 Quantitative Requirements — Applications of this plan requires identification of the index or indices of interest and specification of quantitative requirements for each. When demonstration involves μ_c or μ_{pm}, or a combination of both, consumer's risks will be specified. When demonstration involves M_{max}, the percentile point which defines the specified value of M_{max_c}, will be specified. A minimum sample size of 30 corrective maintenance tasks is required for demonstration of corrective maintenance indices. A minimum sample of 30 preventive maintenance tasks is required where demonstration of preventive maintenance indices by sampling is permitted and is to be accomplished by this method.

A-15.4 Task Selection and Performance — Sample tasks shall be selected in accordance with the procedure outlined in Appendix B. The duration of each shall be recorded and used to compute the following statistics:

$$\bar{X}_c = \frac{\sum\limits_{i=1}^{n_c} X_{ci}}{n_c}$$

$$\bar{X}_{pm} = \frac{1}{n_{pm}} \sum_{i=1}^{n_{pm}} X_{pmi}$$

$$D_t = f_c \bar{X}_c + f_{pm} \bar{X}_{pm}$$

$$\bar{X}_{p/c} = \frac{f_c X_c + f_p . X_{pm}}{f_c + f_{pm}}$$

$$M'_{\max_c} = \text{Antilog}_{\text{Base } e} \frac{\sum\limits_{i=1}^{n_c} L_n X_{ci}}{n_c} + \Psi \sqrt{\frac{\sum\limits_{i=1}^{n_c} (L_n X_{ci})^2 - \frac{\left(\sum\limits_{i=1}^{n_c} L_n X_{ci}\right)^2}{n_c}}{n_c - 1}}$$

where Ψ is the value of the independent variable log normal function which corresponds to the percentile point at which $M_{\max_c}$ has been established. For the two most common percentile points, 90 percent and 95 percent, Ψ is 1·282 and 1·645 respectively.

A-15.5 Accept/Reject Criteria — A table of the normal distribution function shall be consulted for values of ϕ (for a one-tail test) which corresponds to the specified level of consumer's risk β. Table 7 provides values of ϕ which correspond to the most commonly used values of β.

TABLE 7 ϕ vs β

ϕ	β
0·84	20 percent
1·04	15 percent
1·28	10 percent
1·65	5 percent

Accept/reject criteria shall be computed for each specified index in accordance with the following sections.

A-15.5.1 *Test for Mean Corrective Maintenance Time* (μ_c) — The accept/reject value for μ_c is:

$$\overline{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$$

where $\hat{d}_c$ = standard deviation of sample corrective maintenance tasks.

$$\text{Accept if } \mu_c \text{ (specified) } \geqslant \overline{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$$

$$\text{Reject if } \mu_c \text{ (specified) } < \overline{X}_c + \frac{\phi \hat{d}_c}{\sqrt{n_c}}$$

A-15.5.2 *Test for Mean Preventive Maintenance Time* (μ_{pm}) — The accept/reject value for μ_{pm} is:

$$\overline{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$$

where $\hat{d}_{pm}$ = standard deviation of preventive maintenance tasks.

$$\text{Accept if } \mu_{pm} \text{ (specified) } \geqslant \overline{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$$

$$\text{Reject if } \mu_{pm} \text{ (specified) } < \overline{X}_{pm} + \frac{\phi \hat{d}_{pm}}{\sqrt{n_{pm}}}$$

A-15.5.3 *Test for the Mean of all Maintenance Actions* ($\mu_{p/c}$) — The accept/reject value of $\mu_{p/c}$ is:

$$\overline{X}_{p/c} + \phi \sqrt{\frac{n_{pm} (f_c \hat{d}_c)^2 + n_c (f_{pm} \hat{d}_{pm})^2}{n_c n_{pm} (f_c + f_{pm})^2}}$$

$$\text{If } \mu_{p/c} \text{ (specified) } \geqslant \overline{X}_{p/c} + \sqrt{\frac{n_{pm} (f_c \hat{d}_c)^2 + n_c (f_{pm} \hat{d}_{pm})^2}{n_c n_{pm} (f_c + f_{pm})^2}} \text{, Accept}$$

$$\text{If } \mu_{p/c} \text{ (specified) } < \overline{X}_{p/c} + \sqrt{\frac{n_{pm} (f_c \hat{d}_c)^2 + n_c (f_{pm} \hat{d}_{pm})^2}{n_c n_{pm} (f_c + f_{pm})^2}} \text{, Reject}$$

A-15.5.4 *Test for* $M_{\max}$ — The accept/reject value for $M_{\max_c}$ is:

$$M'_{\max_c} + \underset{(\text{ Base } e\text{ })}{\text{Antilog}} \left[\frac{\sum\limits_{i=1}^{n_c} (\, L_n X_{ci} \,)}{n_c} + \Psi \sqrt{\frac{\sum\limits_{i=1}^{n_c} (L_n X_{ci})^2 - \frac{\left(\sum\limits_{i=1}^{n_c} L_n X_{ci}\right)^2}{n_c}}{n_c - 1}} \right]$$

Accept if $M_{\max_c}$ (specified) $\geqslant M'_{\max_c}$

Reject if $M_{\max_c}$ (specified) $< M'_{\max_c}$

A-16. TEST METHOD 10—TEST FOR PERCENTILES AND MAINTENANCE TIME (CORRECTIVE PREVENTIVE MAINTENANCE)

A-16.1 General — This method employs a test of proportion to demonstrate achievement of $\overleftarrow{M}_{ct}$, $\overleftarrow{M}_{pm}$, $M_{\max_c}$ and $M_{\max_{pm}}$ when the distribution of corrective and preventive maintenance repair times is unknown.

A-16.2 Conditions of Use — This method is intended for use in cases where no information is available on the underlying distribution of maintenance task times. The plan holds the confidence level at 75 percent or 90 percent as may be desired and requires a minimum sample size (n_c) of 50 tasks.

A-16.3 Quantitative Requirements — Application of this method requires specification of $\overleftarrow{M}_{ct}$, $\overleftarrow{M}_{pm}$, $\mathrm{M}_{\max_{ct}}$ (95th percentile) or $M_{\max_{pt}}$ (95th percentile) and selection of 75 percent or 90 percent confidence level.

A-16.4 Task Selection and Performance — Sample tasks shall be selected in accordance with the procedures of Appendix B. The duration of each task will be compared to the required value(s) of the specified index or indices ($\overleftarrow{M}_{ct}$, $\overleftarrow{M}_{pm}$, $M_{\max_{ct}}$ and $M_{\max_{pm}}$) and recorded as greater than or lesser than each index.

A-16.5 Accept/Reject Criteria — The item under test shall be accepted when the number of observed task times which exceed the required value of each specified index is less than or equal to that shown in the Tables 8 or 9 corresponding to each index for the specified confidence level.

A-16.5.1 *Test for the Median* — Table 8 is a test of the median for corrective and preventive maintenance tasks. The acceptance level is shown for two confidence levels and a sample size (n_c) of 50 tasks.

TABLE 8 ACCEPTANCE TABLE FOR $\tilde{M}_{ct}$ OR $\tilde{M}_{pm}$

(*Clauses* A-16.5 *and* A-16.5.1)

Sample Size = 50

Confidence Level	
75 percent	90 percent
Acceptance Level	
22	20

A-16.5.2 *Test for* M_{max_c} *and* $M_{max_{pm}}$ — Table 9 is a test for M_{max_c} and $M_{max_{pm}}$ at the 95th percentile. The acceptance level is shown for two confidence levels and a sample size (n_c) of 50 tasks.

TABLE 9 ACCEPTANCE TABLE FOR M_{max_c} OR $M_{max_{pm}}$

(*Clauses* A-16.5 *and* A-16.5.2)

Sample Size = 50

Confidence Level	
75 percent	90 percent
Acceptance Level	
1	0

A-17. TEST METHOD 11 — TEST FOR PREVENTIVE MAINTENANCE TIMES

A-17.1 General — This method provides for maintainability demonstration when the specified index involves μ_{pm} and/or $M_{max_{pm}}$ and when all possible preventive maintenance (PM) tasks are to be performed.

A-17.2 Conditions of Use — All possible tasks are to be performed and no allowance need be made for underlying distribution.

A-17.3 Quantitative Requirements — Application of this plan requires quantitative specification of the index or indices of interest. In addition, the percentile point defining $M_{max_{pm}}$ shall be stipulated when $M_{max_{pm}}$ is of interest.

A-17.4 Task Selection and Performance — All preventive maintenance tasks will be performed. The total population of PM tasks will be defined by properly weighing each task in accordance with relative frequency of occurrence as follows:

> Select the particular task for which the equipment operating time to task performance is greatest and establish that time as a reference period. Determine the frequency of occurrence (f_{pm}) of all other tasks during the reference period. Where the frequency of occurrence of a given task is a fractional number, the frequency shall be set at the nearest integer. The total population of tasks consists of all tasks with each repeated in accordance with its frequency of occurrence during the reference period.

A-17.5 Accept/Reject Criteria

A-17.5.1 *Test for* μ_{pm} — The mean shall be computed as follows:

$$\mu_{\text{pm}} \text{ (Actual)} = \frac{\sum_{i=1}^{k} f_{\text{pm}i} \, (X_{\text{pm}i})}{\sum_{i=1}^{k} f_{\text{pm}i}}$$

where

$f_{\text{pm}i}$ is the frequency of occurrence of the i^th^ task in the reference period.

k is the number of different PM tasks.

$\Sigma f_{\text{pm}i}$ is the total number of PM tasks in population.

Accept if : μ_{pm} (required) $\geqslant$ μ_{pm} (actual)

Reject if : μ_{pm} (required) $<$ μ_{pm} (actual)

A-17.5.2 *Test for* $M_{\text{max}_{\text{pm}}}$ — The PM tasks shall be ranked by magnitude (lowest to highest value). The equipment shall be accepted if the magnitude of task time at the percentile of interest is equal to or less than the required value of $M_{\text{max}_{\text{pm}}}$.

APPENDIX B

(*Clauses* 6.2.2, A-4.1, A-10.4, A-13.1, A-15.4 *and* A-16.4)

MAINTENANCE TASK SAMPLING PLAN FOR FAILURE SIMULATION

B-1. OBJECT

B-1.1 The object of this appendix is to outline a procedure for the selection of a sample of corrective maintenance task for maintainability demonstration when the tasks result from failure simulation.

B-2. APPLICATION

B-2.1 The procedure described in this appendix is applicable only when failure simulation is to be used to generate maintenance tasks. The procedure is applicable to the equipment level and it is presumed that system level maintainability requirements have been allocated to the equipment level for demonstration. The mean estimates for the equipment may be employed to determine achievement of system maintainability requirements.

B-2.2 If sampling of preventive maintenance tasks or servicing is permitted, a procedure and tables similar to that illustrated in this appendix for corrective maintenance shall be developed for each type of task (that is, preventive maintenance, servicing, etc).

B-3. SAMPLE STRATIFICATION

B-3.1 The major objectives of stratification in this standard are to:

a) allow for the selection of maintenance tasks in such a manner that the selection simulates the failures frequency of the test unit in actual operation (units with low, MTBF's will be selected more frequently than units with higher MTBF's); and

b) ensure that a proportionately representative sample of task types/ times are selected.

Proportional stratified sampling may be used for selection of maintenance tasks to be demonstrated using the fixed sample size test methods described in Appendix A. Sequential test method shall employ simple random sampling.

B-4. STRATIFICATION PROCEDURE

B-4.1 Preventive maintenance or servicing tasks should not be combined with corrective maintenance tasks for the purpose of task stratification. For system level demonstration of maintainability requirements, the procedure would be applied to each equipment and through appropriate techniques, the achievement of system maintainability requirements may be demonstrated. Maintenance tasks may be performed concurrently or serially provided that provision has been made to record the expended maintenance time for each maintenance task. The requirement to be demonstrated shall determine the manner in which the data shall be analysed.

B-4.2 The stratification procedure is illustrated in Table 3 by applying the same to a radar equipment consisting of an antenna, receiver/transmitter, frequency tracker, radar set control and drift angle indicator. The procedure adopted here is classified as corrective maintenance.

B-4.2.1 *Column* 1 — Identify the major units which comprise the equipment.

B-4.2.2 *Column* 2 — Subdivide each unit to the functional level at which maintenance for the demonstration is to be performed in accordance with the approved maintenance plan. This level may be an assembly, module, printed circuit card or piece part.

B-4.2.3 *Columns* 3 *and* 4 — For each functional level of maintenance identified in column 2, identify in column 3 the maintenance task or tasks to be performed and in column 4 the estimated mean maintenance time for the task. The maintenance task time shall include the time to perform each element of maintenance time as defined in IS : 1885 (Part 34)-1979*. The maintenance tasks and estimated maintenance time would be derived from a maintenance engineering analysis, a maintainability prediction effort or from a historical data. The same maintenance task such as 'remove and replace' of a module may result from different faults within the module. Column 3 would identify the maintenance task and not the fault or failure which results in the occurrence of the task.

B-4.2.4 *Column* 5 — Determine the failure rate ($F/10^6$h) for each module, printed circuit card, etc, for which the maintenance task was identified in column 3 at the functional level of maintenance identified in column 2. The failure rates used shall be the latest available from the associated reliability programme. If there is no reliability programme, the failure rates may be selected or extrapolated from sources approved by the procurement authority.

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*Electrotechnical vocabulary: Part 34 Reliability of electronic and electrical items (*first revision*).

B-4.2.5 *Column* 6 — Determine the quantity of items in each major unit associated with each task in column 3.

B-4.2.6 *Column* 7 — Determine the duty cycle for each item associated with each task in column 3 (for example, operating time of the receiver to the operating time of the radar, engine operating hours to aircraft flight hours).

B-4.2.7 *Column* 8 — Group together the maintenance tasks identified in column 3 which have:

a) similar maintenance actions, and

b) similar estimated maintenance times.

Note 1 — A maintenance action is an element of a maintenance task. Although the estimated maintenance time for different maintenance tasks may be similar, the actions may be different as one task may involve significant diagnostics and another involve minimum diagnostics but significant access time.

Note 2 — The estimated maintenance times in each group shall be within a range that shall not exceed the smallest value in the group by more than 50 percent.

Note 3 — Task grouping shall be limited to within major units identified in column 1.

B-4.2.8 *Column* 9 — Determine the total failure rate for each task grouping identified in column 8. This total failure rate is equal to the sum of the products of columns 5, 6 and 7 for all tasks within the group.

B-4.2.9 *Column* 10 — Determine the relative frequency of occurrence for each task grouping by dividing the sum of the total failure rate (sum of column 9) into the individual total failure rate for each group.

B-4.2.10 *Column* 11 — This column is to be used where a fixed sampling is employed. A sample of maintenance tasks equal to at least four times the sample size specified for the selected test method (Appendix A) or as specified by the procurement authority shall be allocated among the task groups in accordance with the relative frequency of occurrence of the task group. In Table 3, it is assumed that the test method to be employed requires a sample of 50 maintenance tasks to be demonstrated and, therefore, a sample of 200 tasks (4 × 50) shall be allocated among the task groups as follows:

Group 1 — 0·177 × 200 = 35 tasks.

Group 2 — 0·178 × 200 = 36 tasks.

Group 3 — 0·016 × 200 = 3 tasks, etc.

This allocation is given in column 11. The maintenance tasks allocated to each group shall be randomly selected and identified from the population of maintenance tasks applicable to that group. These randomly selected maintenance tasks shall not be returned to the same pool. When a task group consists of more than one module or assembly such as group 2 of Table 3, the maintenance tasks assigned to the group (36 tasks) shall be allocated to the modules, assemblies, etc, within the group in accordance with the relative frequency of occurrence of maintenance for each module, assembly, etc, within the group. The procedure would be the same as that used to determine the relative frequency of occurrence of the task groups (column 10) would be applied to the modules, assemblies, etc, within the group. This is illustrated below for group 2, Table 3.

Group 2	*Total Failure Rate*	*Relative Frequency of Occurrence*	*Demonstration Population Allocation*
Task A-IF-A	23	0·217	7·8≈8 (0·217×36)
Task B-IF-B	21	0·198	7·4≈7 (0·198×36)
Task C-Amplifier	21	0·198	7·1≈7 (0·198×36)
Task D-Modulator	18	0·170	6·0≈6 (0·170×36)
Task E-Power Supply	23	0·217	7·8≈8 (0·217×36)
	106	1·000	36

B-4.2.11 *Column* 12 — The maintenance tasks to be demonstrated (50 tasks for this example) shall be allocated among the tasks groups in accordance with the relative frequency of occurrence of maintenance for the group as given below:

Group 1 — 0·177 × 50 = 8·85≈9 tasks.
Group 2 — 0·178 × 50 = 8·90≈9 tasks.
Group 3 — 0·016 × 50 = 0·80≈1 tasks, etc.

If a task group consists of more than one module, assembly, etc, such as group 2 of Table 3, the maintenance tasks to be demonstrated from the group (column 12, 9 tasks for this example) shall be allocated to the modules, assemblies, etc, within the group in accordance with the relative frequency of occurrence of maintenance for each module, etc, within the group. This is illustrated below with the sample allocation shown in column 12, Table 3.

Group 2	*Relative Frequency of Occurrence*	*Demonstration Sample Size*
IF-A	0·217	1·95≈2 (0·217 × 9)
IF-B	0·198	1·78≈2 (0·198 × 9)
Amplifier	0·198	1·78≈2 (0·198 × 9)
Modulator	0·170	1·53≈1 (0·170 × 9)
Power Supply	0·217	1·95≈2 (0·217 × 9)
		9

The maintenance task to be demonstrated shall be randomly selected from the maintenance tasks allocated to the group or modules, assemblies, etc, within the group or modules. The maintenance task to be demonstrated shall not be returned to the sample pool and shall be demonstrated once only unless otherwise permitted by the procurement authority.

B-4.2.12 *Column* 13 — This column is to be used where a variable sampling/sequential test method is employed. In this case, a simple random sampling of the total population of maintenance tasks using a random number table based on a uniform distribution from 0 to 1 shall be used. Using Table 3, columns 1 through 10, determine from the relative frequency of occurrence (column 10), the cumulative range of frequency of occurrence for each task group. A maintenance task is selected from that group whose cumulative range of frequency of occurrence includes the number selected from the random number table shall be 'returned' to the table before selecting a second number. The 'specimen' task demonstrated shall be returned to the sample pool.

B-5. FAILURE MODE SELECTION

B-5.1 A failure mode and effect analysis (FMEA), applied to the functional level at which maintenance is to be performed shall be used to determine the failure modes or faults (open, short, etc) which will result in the occurrence of the maintenance task of interest. To avoid duplication of effort, the FMEA shall utilise inputs from the reliability programme efforts and be coordinated with same. The relative frequency of occurrence of the failure mode will determine the fault to be simulated. This procedure is illustrated in Table 10 and explained below.

B-5.1.1 *Column* 1 — Identify the maintenance task of interest.

B-5.1.2 *Column* 2 — Determine the failure modes which will result in the maintenance task of interest.

B-5.1.3 *Column* 3 — Determine the effect of each failure mode identified in column 2.

B-5.1.4 *Column* 4 — Determine the relative frequency of occurrence of each failure mode.

B-5.1.5 *Column* 5 — This column is to be used where a simple random sampling is used. Determine the cumulative range of frequency of occurrence for each failure mode. Using a random number table a number is selected and the failure mode to be induced is that whose cumulative range of frequency of occurrence includes the number selected. The number selected from the rondom number table shall be 'returned' to the table before selecting a second number. The specimen demonstrated shall be returned to the sample pool.

TABLE 10 FAILURE MODE SELECTION

(*Clause* B-5.1)

MAINTENANCE TASK (1)	FAILURE MODE (2)	EFFECT (3)	RELATIVE FREQUENCY OF OCCURRENCE (4) Percent	CUMULATIVE RANGE (5) Percent
Receiver remove/replace	1. Component out of tolerance	1. Noise	0·20	0 — 0·199
	2. Component shorted/open	2. Receiver inoperative	0·35	0·200 — 0·549
	3. Tuning failure	3. Cannot change frequency	0·45	0·550 — 1·00

NOTE — This table is for illustration only and does not reflect real failure modes, etc

INDIAN STANDARDS

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RELIABILITY OF ELECTRONIC AND ELECTRICAL COMPONENTS AND EQUIPMENT

IS :

1885 (Part XXXIX)-1979 Electrotechnical vocabulary : Part XXXIX Reliability of electronic and electrical items (*first revision*)

2612-1965 Recommendation for type approval and sampling procedures for electronic components

7354 Guide on reliability of electronic and electrical items:
  (Part I)-1975 Preliminary reliability considerations
  (Part II)-1975 Managerial aspects of reliability
  (Part III)-1975 Presentation of reliability data on electronic and electrical components (or parts)
  (Part IV)-1974 Collection of reliability, availability and maintainability data from field performance
  (Part V)-1975 Inclusion of lot-by-lot and periodic inspection procedures in specifications for electronic and electrical components (or parts)
  (Part VI)-1983 Inclusion of reliability clauses into specifications for components (or parts) (*first revision*)

7690-1975 Mathematical guide to the terms and definitions for reliability of electronic equipments and components (or parts) used therein

8161 Guide for equipment reliability testing:
  (Part I)-1976 Principles and procedures
  (Part V)-1981 Compliance test plans for success ratio
  (Part VI)-1983 Tests for validity of a constant failure rate assumption
  (Part VII)-1977 Compliance test plans for failure rate and mean time between failures assuming constant failure rate
  (Part XI)-1983 Flow chart describing preparations for and execution of reliability test

9185 Endurance (life) test for electronic and electrical components:
  (Part I)-1979 Thermal endurance
  (Part II)-1979 Mechanical endurance

9186-1979 Guide for screening of electronic and electrical items

9692 Guide on maintainability of equipment:
  (Part I)-1980 Introduction to maintainability
  (Part II)-1980 Maintainability requirements in specifications and contracts
  (Part III)-1981 Maintainability programme

10139-1982 Presentation of reliability, maintainability and availability predictions